Prospective memory across the lifespan – the cognitive instrument in the orchestra of intentional behavior

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1. GENERAL INTRODUCTION

People pursue multiple daily goals from childhood to old age (Louro, Pieters, & Zeelenberg, 2007). Having and pursuing individual goals represents an important brick in the construction of an autonomous, independent and fulfilling life throughout the lifespan (Cockburn & Smith, 1988; Ellis & Freeman, 2008; Kliegel & Martin, 2003). On the way to achieving superordinate goals, a plethora of separate intentions must be completed (Simon, 1994). Thus, successful intentional behavior represents an important capability in human life. However, the separate – sometimes even contradictory – intentions have to be orchestrated in a goal-directed way (Kliegel, Martin, McDaniel, Einstein, & Moor, 2007). How do people manage this orchestration of multiple intentions throughout their lives? A crucial role for successful intentional behavior plays *cognition* and more specifically a process that has been labeled *prospective memory*. The broader aim of the present thesis is to elaborate on the contribution of these cognitive aspects to successful intentional behavior. This is complementary to earlier work examining more social aspects that are also important for successful intentional behavior such as the affective involvement and thus motivation of participants (Altgassen, Phillips, Henry, Rendell, & Kliegel, 2010; Rendell et al., 2011), the social pressure or importance for fulfilling the intention (Altgassen, Kliegel, Brandimonte, & Filippello, 2009; Kliegel, Martin, McDaniel, & Einstein, 2004), personality factors (R. E. Smith, Persyn, & Butler, 2011), the participants' mood (Albinski, Kliegel, Sedek, & Kleszczewska-Albinska, 2012; Altgassen, Kliegel, & Martin, 2009; Harris, 1999), or the source of the intention (Kvavilashvili, 1992). The detailed discussion and examination of these social aspects contributing to intentional behavior will not be part of this dissertation.

In the general introduction of the present thesis, I will provide a framework to organize the existing literature on prospective memory as the representative of the cognitive aspects of intentional behavior. To reach this aim, I will begin with an exemplification of the diversity of prospective memory and the resulting variations in the terminology by clarifying the underlying assumption of this thesis. Therefore, in chapter one, I will present an illustration of the interrelation between the process character of prospective memory, its functional separation into components, a selection of nine paradigmatic factors, and age. I will then clarify what *types* of prospective memory are addressed in this thesis by suggesting a conceptually driven (non-comprehensive) typology (K. D. Bailey, 1994). After formulating the three research questions in chapter two, in chapter three, I will present three empirical studies that examine different mechanisms that contribute to prospective memory performance in various age groups. Finally in chapter four, I will summarize the main findings, discuss a selection of them in a broader context, and give a brief outlook on future research questions.

1.1. Assessment of intentional behavior through prospective memory paradigms

To examine intentional behavior, the term prospective memory was introduced by Meacham and Leiman (1975) at the meeting of the American Psychological Association in Chicago (as cited in Meacham & Leiman, 1982). Although many researchers have since used the term, other terms have been used interchangeably such as “delayed intentions” (e.g., Ellis, 1996), “delayed intentional behavior” (e.g., Zöllig & Eschen, 2009), or “memory for intentions” (e.g., Goschke & Kuhl, 1996).

To clarify, in the current work, I will use the term *prospective memory* and thereby exclusively refer to the *cognitive* aspects of the broader construct of intentional behavior. Nowadays, there is consensus indicating that prospective memory is not a unitary form of memory but instead an umbrella term (Ellis & Freeman, 2008) that covers a variety of different *types* of prospective memory. In a similar way, the term “retrospective memory” also refers to recognition, free recall and cued recall, implicit and declarative memory, immediate recall and delayed recall, and so on.

However, the core principle of prospective memory remains the same regardless of the type. That is, prospective memory, on the one hand, represents a process that can be separated into different *phases* (Ellis, 1996; Kliegel, Martin, McDaniel, & Einstein, 2002; Zöllig & Eschen, 2009). On the other hand, prospective memory consists of two indispensable and interdependent *components* that contribute differentially to prospective memory performance (Einstein & McDaniel, 1996). Furthermore, the prospective memory process, as well as the differential contribution of the two components on prospective memory performance, depend upon various *paradigmatic factors* (for a similar approach see Kvavilashvili, 1992). These paradigmatic factors determine the different types of prospective memory. Moreover, *age* – one focus of this thesis – seems to have an important influence on these links between the process, the contribution of the components, the paradigmatic factors, and ultimately the resulting prospective memory performance (e.g., A. L. Cohen, Dixon, Lindsay, & Masson, 2003; Einstein, Holland, McDaniel, & Guynn, 1992; Einstein, Marsh, Manzi, Cochran, & Baker, 2000; Ellis, Kvavilashvili, & Milne, 1999; Henry, MacLeod, Phillips, & Crawford, 2004). This chain of argumentation represents the pivotal assumption of this thesis and is depicted in the intentional behavior and goal attainment model in Figure 1.

1.2. The intentional behavior and goal attainment model

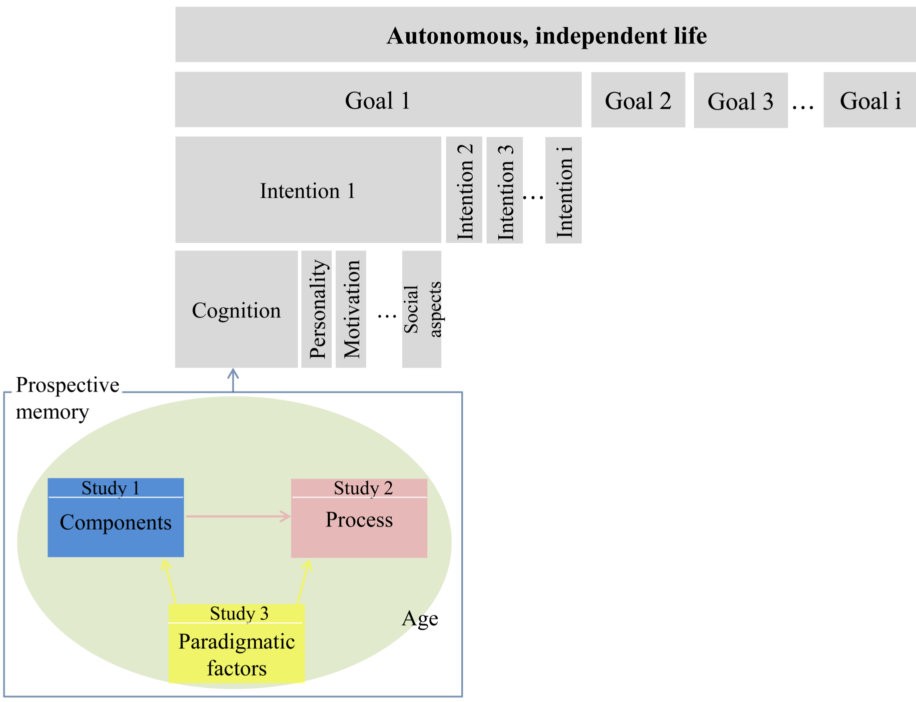

Figure 1. The intentional behavior and goal attainment model as it is used in the current dissertation.

The model assumes that individuals pursue the overarching goal to live an autonomous life across the lifespan. To reach this, multiple simultaneous goals have to be achieved, with each goal requiring the successful completion of various intentions. Some of the intentions might be executable immediately, whereas others must be delayed until the appropriate moment (Ellis & Kvavilashvili, 2001). The completion of an intention is supported by a variety of "instruments". One of these "instruments" is prospective memory and in this model, it signifies the cognitive aspects that support intentional behavior. Prospective memory itself constitutes a process that employs two components that are differentially affected by paradigmatic factors.

1.2.1. The two components of prospective memory

An approach suggested by Einstein and McDaniel (1996; McDaniel & Einstein, 2007) separated prospective memory on a very general level into a prospective and a retrospective component. The prospective component represents the intention itself. That is, it is responsible for initiating and coordinating *that* something has to be done at the appropriate occasion. The retrospective component specifies the "something" and "appropriate occasion" with the intended action and retrieval context (i.e., *what* has to be done *when*?).

Moreover, attempts have been made for moving from the rough separation of these two components towards the more detailed examination and description of specific cognitive functions that underlie prospective memory. These are, on the one hand, executive functions such as planning, shifting, monitoring, inhibition, updating, or working memory (e.g., Craik & Kerr, 1996; Guynn, 2008; Kliegel, Mackinlay, & Jäger, 2008; McDaniel, Glisky, Rubin, Guynn, & Routhieaux, 1999). On the other hand, episodic memory retrieval also plays an important role (e.g., Dobbs & Reeves, 1996; McDaniel et al., 1999; R. E. Smith, 2008; R. E. Smith & Bayen, 2006). It has been suggested that the executive functions are responsible for initiating and coordinating the intention, that is, the prospective component, whereas the episodic memory elements are responsible for the retrospective component (McDaniel & Einstein, 2007).

To successfully complete a prospective memory task, both components and hence a variety of different cognitive functions are indispensable. That is, only the functional interplay of the two components leads to completion of the task. More information about the components and their influence are presented in study 1 and 2 of this thesis.

1.2.2. Prospective memory as a process

The main characteristics of prospective memory are: the capability to form goal-directed intentions, retain them for a variable amount of time, initiate them without any explicit cue, and execute the intended actions in the appropriate moments, thereby approaching the achievement of a personal goal (Kvavilashvili & Ellis, 1996). In its most basic form, this process can be described as consisting of at least four consecutive phases: 1) *intention-formation*, 2) *intention-retention*, 3) *intention-initiation* and 4) *intention-execution* (Ellis, 1996; Ellis & Freeman, 2008; Kliegel et al., 2002; Zöllig & Eschen, 2009).

During the first phase of intention-formation, individuals consciously formulate the intent, including a specific action and the retrieval context. Thus, individuals plan what action they will execute at what occasion. In phase 2, the intention leaves the focus of attention as a result of conducting other activities. It is at this time stored in long-term memory. From studies that combine temporally high-resolution measures of the electrophysiological brain activity (EEG) of prospective memory retrieval and behavioral analyses, it is known that phases 3 and 4, the intention-initiation and -execution, include a distinct order of subphases (West, 2011). Phase 3 begins with the detection of the retrieval context, that is, the prospective memory cue. Once the cue is detected, the attention is switched from the ongoing activity toward the prospective memory task. The fourth phase sets off with the retrieval of the intention content from memory, followed by the execution of the intended action itself. Phases 3 and 4 can be summarized as the retrieval interval of a prospective memory task (Ellis & Freeman, 2008; Zöllig & Eschen, 2009).

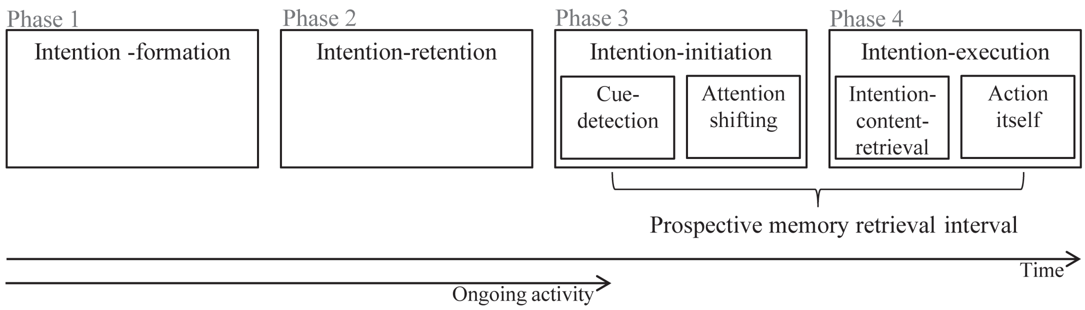

Figure 2. **The prospective memory process.** Illustration of the prospective memory process based on Ellis (1996), Kliegel et al. (2002) and Zöllig and Eschen (2009), expanded with its subphases based on electrophysiological results (West, 2011).

This process (see Figure 2) appears in very different forms not only in our everyday lives, but also in the empirical research literature. The specific configuration of the prospective memory process thereby – as mentioned previously – depends on a number of paradigmatic factors that I will describe in more detail under 1.3.

1.2.3. The integration of components and phases of prospective memory

It is important to note that the two approaches presented under 1.2.1 and 1.2.2 are not separable. In fact, the cognitive functions which are summarized in the two components are differentially active across the phases of the process (Kliegel et al., 2002; Zöllig & Eschen, 2009). Therefore, it seems reasonable to not only ask about "what component" or "which phase of the process is important", but instead to also combine the two approaches and rather ask about "what cognitive function plays which role in which phase?"

1.3. A typology of prospective memory tasks

Even when researchers use the term prospective memory to refer to the cognitive aspects of intentional behavior (as I do in the current work), they differ in terms of the specific task with which they examine it. The specific configuration of the basic multi-component process of prospective memory depends upon a variety of paradigmatic factors (see Figure 1). Specific combinations of paradigmatic factors result in a variety of different types of prospective memory that are measured. Depending on the configuration of paradigmatic factors that researchers apply, this might lead to very different, sometimes even contradictory findings (see below the "age - prospective memory paradox"), although in principle, they all measure prospective memory. Accordingly, it might be that these are not "real" contradictory findings, but just the result of comparing different types and thus aspects of prospective memory. More precisely, I argue that prospective memory remains in principle the same cognitive ability regardless of the configuration of paradigmatic factors. That is, the process does basically not change, there is always phase 1, phase 2 etc., and there is always a prospective and a retrospective component. However, the process can present itself in very different forms, depending on the configuration of the paradigmatic factors, challenging the two components or requiring the cognitive functions to different degrees. I will illustrate this point with an example below (see description of the paradigmatic factor a) in Table 1).

Since the broad aim of this thesis is to examine the contribution of prospective memory to an autonomous life from childhood to old age, it might be expedient to exemplify a selection of paradigmatic factors. The first eight factors (a) - h)) are those, that have been studied mostly in the past (e.g., Kliegel, McDaniel, & Einstein, 2008). The last of the nine factors, attention allocation, represents a paradigmatic factor that has not been studied in the past, but will be the target of the third research question of this thesis (see 2.3).

Table 1. A typology of prospective memory.

Paradigmatic factor	vs.	
a) Environment	laboratory	naturalistic
b) Type of cue	event	time
c) Cue prominence	high	low
d) Intention alteration	no	yes
e) Number of simultaneous intentions	single	multiple
f) Length of delay	short	long
g) Cue frequency	high	low
h) Execution after cue	instantly	delayed
i) Attention allocation	no	yes

The suggested factors are independent; for example a laboratory paradigm can apply either type of cue, can either alter intentions or not and so forth. Hence, between the factors, all combinations are possible. Within a factor, the two antitheses are sometimes incompatible (e.g., either the paradigm includes a single intention *or* multiple) and sometimes they represent stages of a continuum (e.g., the length of delay). It is ideal for all prospective memory researchers to explicitly clarify what constellation of factors they use and hence, what type of prospective memory they are exploring. This might help to improve our understanding of the function that prospective memory holds in pursuing multiple individual goals across the lifespan and resolve the discussions about contradictory results of different experimental manipulations.

It is not the aim of this thesis to distinguish all the 512 (=2^9) different combinational types of prospective memory with one paradigm. Rather this suggestion for a typology serves to delineate the types of prospective memory that are investigated in the following discussion from the types that are not under empirical investigation herein.

1.3.1. A brief description of nine paradigmatic factors

In this paragraph, I will illustrate nine paradigmatic factors that influence the configuration of the prospective memory process and the relative contribution of the components. I will not discuss all the (2 x 2 x 2 x 2 x 2 x 2 x 2 x 2 x 2) different combinations but instead focus on one factor at a time. For each factor, I will give examples of prototypical paradigms of the two extreme poles (if the factor represents a continuum), or of the two antitheses. If available, I will also report findings with respect to age-related differences.

a) Environment

The first factor of this typology is the *environment* in which the prospective memory task is measured, that is in either a *naturalistic* or a *laboratory* setting. In the former, the prospective memory task is embedded in the individuals' everyday lives. For example, the experimenter may ask the participants to always lock the back door, the first time after they put on outdoor shoes and/or a coat (Experiment 2, Rendell & Craik, 2000). In the laboratory setting, the prospective memory task is an artificial task, nowadays often on a computer, such as pressing a specific button every time a specific cue, for example whenever a particular target word, occurs during an ongoing activity (Einstein & McDaniel, 1990). This distinction between naturalistic and laboratory settings is especially interesting in regard of age-related differences across adulthood. Results collected with laboratory paradigms versus in naturalistic settings led to the formulation of the "age - prospective memory paradox" (e.g., P. E. Bailey, Henry, Rendell, Phillips, & Kliegel, 2010; Maylor, 1990; Rendell & Craik, 2000; Schnitzspahn, Ihle, Henry, Rendell, & Kliegel, 2010). Whereas in the laboratory, young adults consistently outperform older subjects in prospective memory tasks, in naturalistic settings, seniors perform better than young adults

(Henry et al., 2004). The main reason for the age benefit in naturalistic tasks has been speculated to lie in differential daily activity absorption of young and old adults (Phillips, Henry, & Martin, 2008). One reason for differential absorption (besides the number of tasks) might be the routine and structure of the daily activities. More routine means better knowledge and familiarity with the progress of the "ongoing activity" (Zöllig, Mattli, Sutter, Aurelio, & Martin, 2012). The everyday lives of older adults may accordingly be more structured and less absorbing. This setting enables old adults to (compensatory) reallocate resources away from the ongoing activity towards the prospective memory task. As a result, old adults perform better than young adults. In a laboratory setting, however, for both young and old adults, the ongoing activity is unfamiliar and hence highly absorbing. Without the possibility of resource reallocation, young adults hence outperform old adults consistently (Henry et al., 2004). Support for this argumentation comes from Zöllig et al. (2012). In this study, we could show that increasing the familiarity with the ongoing activity sequence in the laboratory enhances prospective memory performance in older subjects. However, this increase in performance is the result of changed environmental suppositions (i.e., resource reallocation), but not of the "pure" cognitive ability of prospective memory itself.

Moreover, the basic process of prospective memory remains the same whether measured in the laboratory or in a naturalistic setting. What changes is the configuration: that is, the specific characteristics of each phase and thus the demand upon the specific cognitive functions as a result of the environmental settings. To take this assumption one step further, I argue that the "pure" prospective memory ability itself is similarly impaired in older adults whether it is used in the laboratory or in a naturalistic setting. The different results and thus the paradox are a result of a strong interaction between the environmental setting and the other instruments that contribute to successful intentional behavior, such as motivation, personality, routine and so on.

b) Type of cue

The intended action within an intention can be initiated by two different *types of cues*: either a temporal criterion or an event. These two conceptually different types of prospective memory have been labeled *time-based* and *event-based* prospective memory (Einstein & McDaniel, 1990). In everyday life an example of a time-based task would be taking medication at 9 am, or remembering to turn off the oven after 20 minutes. In the laboratory, this type of prospective memory was tested for example by asking participants to pull a lever every 2 minutes while performing a working memory task (Experiment 2, Park, Hertzog, Kidder, Morrell, & Mayhorn, 1997). Examples for an event-based task in everyday life would be posting a letter in the mailbox when passing by or taking medication with breakfast. In the laboratory, the aforementioned example of pressing a specific button every time a specific event such as a specific target word occurs (Einstein & McDaniel, 1990) represents an event-based task. The type of cue alters the degree of environmental support and self-initiated processing (Craik & Kerr, 1996; Einstein, McDaniel, Richardson, Guynn, & Cunfer, 1995). The major difference between these two kinds of tasks is, according to Einstein, Holland, McDaniel, and Guynn (1992), that some kind of external cue that reminds persons of their intention only exists in event-based prospective memory tasks. This difference implies that in time-based tasks the demands upon the self-initiated processing are even higher (Craik, 1986 as cited in Zacks, Hasher, & Li, 2000). As attentional resources that are necessary for self-initiated activity change across the lifespan (Zelazo, Craik, & Booth, 2004), age-related differences in (laboratory) prospective memory performance are more pronounced in time-based tasks than in event-based tasks (Henry et al., 2004; Yang, Chan, & Shum, 2011).

c) Cue prominence

By *cue prominence* I am subsuming two characteristics of the prospective memory cue, that is cue *focality* and cue *salience*. The effects of cue characteristics have been studied extensively especially in the context of the multiprocess framework (McDaniel & Einstein, 2000). A focal and salient cue involuntarily captures an individual's attention or switches the attention from the ongoing toward the prospective memory task, respectively. A nonfocal or nonsalient prospective memory cue requires more attentional effort to be detected as such. If the ongoing task is a semantic categorization task and the prospective memory cue is the category "animal", this cue would be focal and salient. If the ongoing task is a lexical decision task and the prospective memory cue is a specifically colored frame around the screen, this is a nonfocal and nonsalient task (Einstein & McDaniel, 2005). With respect to age, McDaniel, Einstein and Rendell (2008) could show that prominent cues diminish age-related differences as a result of less attentional resources being needed to complete the task because prominent cues more readily trigger automatic prospective memory task execution.

d) Intention alteration

By *intention alteration* I am referring to the possibility of changing intentions within the course of a task. The majority of experimental prospective memory paradigms so far do not alter the intention. That means that participants form one single intention at the beginning of the task, and must maintain this exact intention across the entire task. For example in the study of West, Krompinger and Bowry (2005), participants were instructed to always press the C- or the M-key upon detection of the letters D or M, respectively, within a n-back letter comparison task. In contrast, if the intention is altered after the execution of one intention, its content must be updated. That is, a new intention has to be formed, retained, initiated and executed, while the previous intention must be cancelled. For example, two studies that used such an intention alteration-approach were conducted to analyze the electrophysiological activity during intention-formation trials and subsequent prospective memory performance (West & Ross-Munroe, 2002; Zöllig, Martin, & Kliegel, 2010). In these studies, four different intentions were possible across the course of the task, although only one was active at a time. We adopted this procedure of four possible changing intentions within the paradigm used in empirical studies 1 and 2 presented later in this thesis. With respect to age-differences, no study was found that explicitly examined the comparison of intention alteration versus no intention alteration. Changing intentions require that the intention content be updated again and again. Moreover, executive functions, including updating (Miyake et al., 2000) are known to undergo clear changes across the lifespan (Zelazo et al., 2004), which would, assumedly, in turn have an influence on the effect of intention alteration upon prospective memory performance across the lifespan.

e) Number of simultaneous intentions

As mentioned above, in everyday life people often have a couple of intentions simultaneously activated. The *number of simultaneous intentions* can however vary greatly. Certainly, this variation influences the demands on both of the components of prospective memory (i.e., the underlying cognitive functions) and thus it seems not surprising that this might have an effect on performance.

Most of the studies on prospective memory used paradigms in which only one intention is active at a time. That is, it might be altered within the task (see paradigmatic factor d) above) but, at any given time, only one intention is active. For example, in experiment 1 of Einstein and McDaniel (1990), participants were instructed to always press a specific button upon occurrence of the word "rake" within a short-term memory task. This was the only intention participants had to pursue. The characteristic of multiple simultaneous intentions has experimentally been attempted to be captured by Kliegel and colleagues (e.g., Kliegel, Eschen, & Thöne-Otto, 2004; Kliegel, Martin, & Moor, 2003; Kliegel, McDaniel, & Einstein, 2000). They proposed a prospective memory paradigm based on the six-element task of Shallice and Burgess (1991). The basic principle in terms of the paradigmatic factor described here is that subjects must execute six tasks after a previously (self-) formed plan. Along the task course they must hold these different preserved intentions and then execute them one at a time, each at its appropriate moment. A study that analyzed the effects of the number of the intentions on the electrophysiological activity of the brain was conducted by West, Wymbs, Jakubek and Herndon (2003). They showed that an increasing number of simultaneous intentions challenged, not surprisingly, the retrospective component to a stronger degree. More precisely, the number of intentions influenced the brain's electrophysiological activity associated with intention content retrieval, but not the activity that was associated with cue-detection.

There is no study available that directly compared age-related differences in paradigms with one intention versus paradigms with multiple simultaneous intentions. However, to successfully complete all intentions, the latter assumedly put higher demands upon a number of executive functions such as attentional resources, planning, monitoring, updating, and shifting (Kliegel, Mackinlay et al., 2008). Accordingly, age-related difference can be expected to be more pronounced in paradigms with multiple simultaneous intentions. At the same time, paradigms with multiple simultaneous intentions possibly provoke greater use of non-cognitive strategies such as external memory aids to complete the tasks.

f) Length of delay

The duration of phase 2 of the prospective memory process, that is, the intention-retention phase, can vary widely from seconds, to minutes, hours, days, months, and years (West & Ross-Munroe, 2002). All laboratory prospective memory tasks have – due to pragmatic reasons – rather short delays between the intention formation and the intention execution as compared to some tasks of our everyday lives (e.g., one has to remember and congratulate one's mother only once a year for her birthday). However, research examining the effect of the *length of delay* in laboratory prospective memory tasks has revealed equivocal findings as summarized by Ellis and Freeman (2008). Specifically, despite an intuitive assumption, there have been studies showing no decline in performance as a function of increasing delay between the formation of the intention and the execution of the intended action (Einstein et al., 1992; Guynn, McDaniel, & Einstein, 1998; Stone, Dismukes, & Remington, 2001). Others found even increased performance after a longer delay (Hicks, Marsh, & Russell, 2000). And again others found lower performance after a longer delay (Meacham & Leiman, 1982).

Age-related differences in terms of the length of delay have not been studied extensively. One study conducted by Einstein et al. (1992) found that in both young and old adults the length of delay did not influence prospective memory performance. However, taking into account findings about differential trajectories of forgetting curves across the lifespan (Brainerd, Reyna, Howe, Kingma, & Guttentag, 1990), one could expect age-related differences in the effects of changing delay periods.

g) Cue frequency

Depending on the intention, the occasion to execute it might occur very often and routinely or very rarely or even only once in one's daily life. For example, consider when a teacher tells a child to pass a message to its parents. This specific intention (with content xy) only has to be passed once. On the other extreme, if garbage collection is always on Monday, the intention to put the bag out occurs relatively frequent (every 7^{th} day). A study conducted by Ellis et al. (1999) examined what effects the varying frequencies of prospective memory cues have on overall performance. In the experiments of their study, the independent variable was frequency in the sense of "prospective memory cue per ongoing activity trial": that is either "high" frequency (experiment 1: 1 prospective memory cue on 20-25 ongoing activity trials; experiment 2: 1 prospective memory cue on 100 ongoing activity trials) or "low" frequency (experiment 1: 1 prospective memory cue on 40-45 ongoing activity trials; experiment 2: 1 prospective memory cue on 600 ongoing activity trials). The dependent variable was overall prospective memory performance. Surprisingly, their results indicated that cue frequency did not have a reliable effect on overall performance. However, as I will argue under factor i) – though from a different perspective – the difference between many and few prospective memory events may lie elsewhere, namely in the chance for attentional resources to change across the repetition of the task.

h) Execution after cue detection

In many situations in our everyday lives, an intention cannot be executed instantly after the detection of the cue. Instead, the intention has to again be briefly delayed until the appropriate situation arises. For instance, imagine my brother told me to remind a mutual friend that he owes my brother 10 francs. As soon as I meet my friend, I remember this intention. Since I am, however, a polite person, I first greet my friend, ask him how he is and then finally remind him of the debt. During this secondary delay, the intention does not necessarily leave the focus of attention, but instead the execution is just "postponed" (i.e., the intention stays in the phonological loop of working memory, Kliegel & Jäger, 2006). This special kind of prospective memory task has been labeled "delayed-execute prospective memory" (McDaniel, Einstein, Stout, & Morgan, 2003). It has been shown that even a very short secondary delay decreases prospective memory performance dramatically (Einstein et al., 2000; Einstein, McDaniel, Williford, Pagan, & Dismukes, 2003), particularly for older adults (Kliegel & Jäger, 2006). These results led to the conclusion that such a secondary delay requires the formation of a new plan and that in turn requires more working memory resources (Einstein et al., 2000). Working memory in turn is subject to age-related variations across the lifespan (e.g., Gathercole, 1999; Park et al., 2002).

i) Attention allocation

In everyday life, multiple intentions simultaneously compete for available resources all the time. It seems therefore reasonable to expect that the limited availability of attentional resources must sooner or later be reallocated from one intention to another (Simon, 1994; Zacks et al., 2000). A prerequisite for reallocation of attentional resources is the release from pursuing the originating intention. Moreover, if we assume that attentional resources decrease across adulthood (Salthouse, 1991), the question poses itself: how is this prerequisite for managing multiple intentions accomplished by older adults? McDaniel and Einstein (2000) argue that given the prevalence of prospective memory tasks in our everyday life, it would be nothing but adaptive to sometimes rely on more automatic processes and thereby free up attentional resources. So far, very little research exists that has analyzed a possible change from more resource-demanding to more automatic prospective memory retrieval within subjects systematically. One study that could be considered was conducted by McDaniel, Bugg, Ramuschkat, Kliegel, and Einstein (2009). Although with a focus on age-related differences in attentional resource allocation policies with respect to repetition errors (i.e., erroneously executing an intended action twice), they examined attentional resource allocation of young and old adults in a high-frequency time-based prospective memory task by analyzing changes in ongoing task reaction times across blocks of trials. However, their data revealed a non-significant effect of block and no interaction with age. Another study (Experiment 2, McDaniel et al., 2008) focusing on the distinction between focal versus non-focal prospective memory cues with respect to the attentional resource allocation found decreasing costs of the prospective memory task throughout the experiment. They interpreted this finding as indication for declining monitoring across the course of the experiment with a non-focal cue. One could argue that as the experiment progressed, capacity-consuming monitoring decreased and this might indicate a release of attentional resources, thus some kind of automatization. However, we are currently missing further direct evidence for changes of resource allocation (i.e., signs of automatization) within the course of successful event-based prospective memory task completion.

To close the circle from factor g) above: If we assume that automaticity occurs as a result of repeated exposure (Schneider & Shiffrin, 1977), it seems logical to infer that high-frequency paradigms lead to faster automatization than low-frequency tasks. Or, in other words, frequent intentions in comparison to rare intentions might not be executed more successfully per se (factor g), but instead with less attentional effort. In the empirical study 3 of the present thesis, I will come back to this point and report new findings with respect to automatization in an event-based prospective memory task.

2. AIMS AND RESEARCH QUESTIONS

2.1. Question 1: How does prospective memory behavior differ across the lifespan and what is the relative contribution of each of the two components?

To answer the first research question of this thesis, three goals are pursued. First, measurement of prospective memory performance across six age groups with only one paradigm. Second, investigation of the relative contribution of the prospective and the retrospective component of prospective memory to its developmental trajectory across the lifespan (i.e., the blue box in Figure 1). The third aim in study 1 is the examination of positive and negative rehearsal effects: that is effects of prompted recall of the intention content (i.e., checking the knowledge of the retrospective component) – preceding or following the prospective memory task – upon prospective memory performance.

Previous research suggests the overall performance in prospective memory tasks sharply increases from childhood to young adulthood and steadily decreases from young adulthood to old age (Kliegel, Mackinlay et al., 2008; Zimmermann & Meier, 2006; Zöllig et al., 2007). However, studies investigating the impact of the cognitive functions underlying the prospective and the retrospective component on the age-related trajectory in performance report discordant results. Additionally, both, studies claiming retrospective component functions as well as studies claiming prospective component functions to be more responsible for this developmental path can be found (e.g., Ceci, Baker, & Bronfenbrenner, 1988; A. L. Cohen et al., 2003; Einstein et al., 1992; Kerns, 2000; Logie, Maylor, Della Sala, & Smith, 2004). Moreover, other studies suggest that there might be differential processes responsible for the “rise and fall” of prospective memory across the lifespan (e.g., Zimmermann & Meier, 2006; Zöllig et al., 2007). As mentioned above, these contradictory findings may, however, be more a result of comparing measures from different paradigmatic factor combinations than substantial competing findings. Therefore, in study 1, the relative contribution of the two components to prospective memory performance is disentangled with only one paradigm applied to a lifespan sample.

2.2. Question 2: How do the temporal dynamics differ between successful and failed prospective memory retrieval? Or in other words: when does the error happen?

After having analyzed the question about the relative contribution of the two components in the first empirical study, the second research question is concerned with age-related differences in the prospective memory process (i.e., the red box in Figure 1). More precisely, the interest lies on developmental differences at the point within the prospective memory process at which the cognitive functions lead to a failure. Nevertheless, not the entire process but only the retrieval interval, that is phases 3 and 4, the intention-initiation (with its subphases) and -execution are analyzed. To do this, the electrophysiological correlates of prospective memory during these phases are measured.

With a purely behavioral approach it is difficult to further segregate the phases of the prospective memory process. Simple average performance measures merely capture the outcome of all cognitive mechanisms active in one phase and obliterate the separate contributions of each (Marsh, Hicks, & Watson, 2002). However, a missed prospective memory response can emerge from errors in any of the appertaining phases and hence, contributing cognitive mechanisms (Ellis & Freeman, 2008). Due to its high temporal resolution, the analyses of the electrophysiology (i.e., EEG) during successful (hits) and failed (misses) prospective memory trials enable the temporal dynamics of the ongoing neural processes within one phase of the prospective memory process to be addressed. Based on previous research that provided information about the link between time windows, electrode saliences, and underlying cognitive mechanisms, EEG analyses allow inferences regarding the content-relevant meaning of differences between the electrophysiology of prospective memory hits and misses. Subsequently to research question 1 (see point 2.1), the goal of the second empirical study is to go one level deeper and investigate mechanisms within one phase of the prospective memory process that lead to the age-related differences in performance in children, younger, and older adults.

2.3. Question 3: How do the cognitive functions supporting prospective memory retrieval change across the repetition of a prospective memory event and are there age-related differences in this change?

The third research question aims at analyzing the contribution of one specific factor to prospective memory performance (i.e., the yellow box in Figure 1). More precisely, the third study in this thesis aims at gaining more knowledge about the influence of factor i), the release and hence, possible reallocation of attentional resources across multiple repetitions of a prospective memory event.

The idea that the number of repetitions of a prospective memory cue might influence the type of the prospective memory task is not new (see above paradigmatic factor f) and Ellis et al., 1999; Maylor, 1996). It can be expected that a variation in the number of repetitions of a prospective memory cue leads to considerable variation in the mechanisms recruited to perform the prospective memory task. As described earlier, Ellis et al. analyzed overall performance differences as a result of cue frequency alterations and did not find any effects of cue frequency on prospective memory performance. However, following the idea that the resources to accomplish the task might change *within* the course of the task (paradigmatic factor i)), the third research question aims at capturing the release of attentional resources within subjects from a longitudinal perspective. From other fields of cognitive research (e.g., source memory, Dywan & Jacoby, 1990) it is known that higher familiarity and repeated exposure with a stimulus mediates automatic retrieval (Schneider & Shiffrin, 1977; Zacks et al., 2000).

The third research question thus is: How do cognitive mechanisms supporting prospective memory tasks change across the repetition of a prospective memory cue (i.e., longitudinally) and are there age-related differences in these changes?

2.4. How can these questions be examined? – The paradigmatic operationalization of the research questions

As mentioned above, in my opinion it is ideal for all prospective memory researchers to explicitly specify what combination of factors they are examining to clarify how the results can be embedded and linked to other studies. Accordingly, two specific paradigms enable the detailed examination of the three research questions of this thesis:

Studies 1 and 2

Studies 1 and 2 use a paradigm that encompasses a prospective memory measure with a) a laboratory task, using b) an event-based, c) not prominent cue, requiring, d) changes between four different intentions of which however e) only one is active at a time. Cues occur after f) short delays and with g) rather high frequency and the intentions have to be executed h) instantly. Furthermore, the paradigm does i) not allow the examination of changing attentional resources across trials.

The specific combination of factors is partly due to requirements for EEG-analyses and pragmatic consequences; these are factors a), b), and g) and factors f) and h), respectively. The factors c) and d) are the consequence of the specific research questions; that is age-related differences in performance and electrophysiology and the rehearsal effects (see 3.1.2 or 3.2.2 for an exact description of the paradigm). Factor e) was chosen to avoid further increases in difficulty and to downsize demands upon executive functions and the chance of non-cognitive strategy use.

Study 3

Study 3 uses a paradigm that encompasses a prospective memory measure with a) a laboratory task, using b) an event-based, c) not prominent cue, requiring d) no change of the e) single intention across the task. Cues occur after f) short delays, with g) high frequency and the action must be executed h) instantly. The paradigm does i) allow the examination of changes of attentional resource allocation across trials.

Here, factors a) and b), and factors f) and h), respectively, were set due to EEG-analyses requirements or pragmatic consequences. Factors c), d), e), g) and i) depict the prerequisites for answering our research question about changes in attentional resources (see 3.4.2 for the exact description of the task).

3. EMPIRICAL STUDIES

3.1. Study I: Prospective memory across the lifespan: Uncovering the contribution of different components[1]

3.1.1. Introduction

Prospective memory (PM) is defined as remembering to perform an action at a future point in time in the absence of an external prompt (Brandimonte, Einstein, & McDaniel, 1996; Ellis, 1996; Ellis & Freeman, 2008). Efficacy of PM performance is strongly related to the development and maintenance of autonomy in everyday life across the lifespan (Ellis & Freeman, 2008; Kvavilashvili, Messer, & Ebdon, 2001; McDaniel & Einstein, 2008). The mechanisms underlying the "rise and fall" of PM performance across the lifespan are currently under debate. One of the main focuses in this discussion lies on the relative contribution of retrospective memory elements and purely prospective memory elements to PM performance. Additional information in this discussion might be gained by including the examination of age-related rehearsal effects of the retrospective memory elements on PM performance. It has been shown that reminders that referred to both the intended action and the retrieval context did improve subsequent PM performance in young adults (Guynn et al., 1998). Accordingly, the main goal of the present study was to examine a rather large lifespan sample covering six age groups and to investigate age-related mechanisms underlying PM performance. We did this by separately considering retrospective memory elements and purely prospective memory elements and by designing a paradigm that enabled us to examine (positive and negative) rehearsal effects.

PM tasks are multidimensional and involve several qualitatively different components, including executive functions (e.g., planning, shifting between different tasks, monitoring of the environment, inhibition of prepotent responses, Craik & Kerr, 1996; Guynn, 2008; Kliegel, Mackinlay et al., 2008) and retrospective, episodic memory elements (e.g., remembering the retrieval context and what the

[1] A similar version of this chapter has been submitted for publication at "Aging, Neuropsychology, and Cognition" (Mattli, Zöllig, Studerus-Germann, & Brehmer)

required action is, Dobbs & Reeves, 1996; Einstein & McDaniel, 1990; R. E. Smith & Bayen, 2006). Einstein and McDaniel (1990) named these two cognitive components of PM the *prospective component* and the *retrospective component*, respectively. The prospective component reflects the involved executive functions that are mostly supported by the frontal cortex (Lezak, 1995; McDaniel et al., 1999), while the retrospective component corresponds to retrospective, episodic memory elements that are mostly located in the medial temporal lobes (e.g., hippocampus, J. D. Cohen & O'Reilly, 1996; Nyberg, McIntosh, Houle, Nilsson, & Tulving, 1996). The prospective component comprises the *intent* itself and is responsible for remembering that one has to do something at a certain point in the future. The intent is the immediate cause of the action (Brand, 1984). In contrast, the retrospective component encompasses the appropriate *retrieval context* and the intended *action*. It is, hence, responsible for remembering the *intention content*, or what to do and when to do it. Success in a PM task requires successful interaction of both components (R. E. Smith & Bayen, 2006) while a failure in one aspect of the components leads to a failure of the whole task (R. E. Smith, 2008).

When considering developmental aspects of PM performance, continuous changes are apparent throughout the lifespan. Almost all studies have considered selected age spans and applied age-specific paradigms. For example, Kvavilashvili et al. (2001) explored PM performance in childhood (for a recent overview see Kvavilashvili, Kyle, & Messer, 2008) showing that already preschoolers have PM competences that continue to develop through adolescence (Ceci et al., 1988; Guajardo & Best, 2000; Kerns, 2000; Kliegel & Jäger, 2007; Martin & Kliegel, 2003; Somerville, Wellman, & Cultice, 1983). After the age of around 25, PM performance starts declining with an acceleration of decline after 70 years towards very old age (Kliegel, Mackinlay et al., 2008; Mantyla & Nilsson, 1997; Uttl, 2008). However, relatively little is known about processes that underlie this “rise and fall” in performance and whether they are similar or distinct across the lifespan (Kliegel, Mackinlay et al., 2008). Only a few studies have assessed PM performance in a lifespan sample within one paradigm (e.g., Kliegel, Mackinlay et al., 2008; Zimmermann & Meier, 2006, 2010; Zöllig et al., 2007). They found support for an inverted U-shaped function of PM performance across the lifespan and evidence for assuming age-related differences in how cognitive components affect performance in childhood and old age.

These findings appear very plausible also in light of the cognitive resources involved for completing a PM task (e.g., executive functions and aspects of retrospective, episodic memory) and their changes across the lifespan. The functionality of executive and retrospective memory processes increases during childhood and decreases towards old age (Kausler, 1994; Kray, Eber, & Lindenberger, 2004; Schneider & Pressley, 1997; Zelazo et al., 2004). Current research has aimed at examining the impact of different cognitive components on these age-related differences in PM performance. However, the results are equivocal. Regarding developmental changes during childhood, evidence suggests that improvements in PM between 7 and 12 years of age reflect an increase in the efficient use of strategic monitoring associated with the prospective component of PM (Ceci et al., 1988; Kerns, 2000). In contrast, other findings indicate that improvements in PM between 7 and 10 years of age may arise from an increase in the efficiency of processes underlying the retrospective component of PM (R. E. Smith, Bayen, & Martin, 2010). In the domain of aging research, for example Einstein, Holland, Mc Daniel, & Guynn (1992) claimed that it is mainly the retrospective component that is responsible for the decline in old age, whereas other authors found evidence for the prospective component being more susceptible to increasing age (A. L. Cohen et al., 2003; Kidder, Park, Hertzog, & Morrell, 1997; Logie et al., 2004; R. E. Smith & Bayen, 2004, 2006).

The current study

In the present study a particular task was utilized allowing the investigation of specific aspects of PM. First, PM performance across six age groups was assessed using a modified version of the PM encoding-retrieval paradigm (West & Ross-Munroe, 2002; Zöllig et al., 2007). The modification was made with respect to the separate assessment of the intention content (i.e., intended action and retrieval context that constitute the retrospective elements of the PM task). With this approach we were also able to analyze age-related effects of intention content rehearsal on PM performance.

This study pursued three main goals: First, replication of the previously described "rise and fall" of PM performance across the lifespan in a rather large sample including six different age groups. Second, examination of the relative contribution of the purely prospective memory elements (i.e., prospective component of PM) and the retrospective memory elements (i.e., retrospective component of PM) to age-related changes in PM performance across the lifespan. Third, investigation of age-related effects of intention content rehearsal on following PM trials. With this approach we wanted to examine if the *correct* explicit retrieval of the intention content before the actual PM task serves as reminder for this task and potential age-related differences therein. Additionally, we examine if the *incorrect* retrieval of the intention content before the actual PM task creates an intrusion effect that interferes with the correct execution of the following PM task and potential age-related differences therein.

3.1.2. Methods

Participants

The sample included individuals' between 7.5 and 83 years of age that were divided into six age groups: young children (*N* = 16 (9 f), *M* = 8.6 years, *SD* = 0.6), old children (*N* = 17 (5 f), *M* = 11.9 years, *SD* = 0.4), young adults (*N* = 19 (10 f), *M* = 24.8 years, *SD* = 3.2), middle-aged adults (*N* = 14 (8 f), *M* = 40.5 years, *SD* = 2.7), young-old adults (*N* = 17 (6 f), *M* = 61.1 years, *SD* = 3.6) and old-old adults (*N* = 16 (4 f), *M* = 75.7 years, *SD* = 3.4). All participants were native German speakers, in good health and none reported brain injuries, psycho-affective medication, drug consumption or diseases affecting brain functioning. A standard psychometric battery was used to screen for participants scoring more than one standard deviation below age appropriate norms on verbal intelligence, psychomotor speed, memory span, and planning ability. The data of six participants were excluded due to technical problems (one young child and three middle-aged adults), poor performance on the psychometric battery (one old-old adult), or difficulties in color discrimination (one old-old adult); resulting in data for 99 participants being included in the analyses.

Children were recruited at school either by their teachers or through the distribution of flyers that were approved by the school authority. Young and middle-aged adults were recruited through placards on a notice board at the University of

Zurich and at centers for continuing education around Zurich. Old adults were recruited at a lecture for senior citizens at the University of Zurich. The experiments were conducted in agreement with the declaration of Helsinki. Informed consent was obtained from all participants or their lawful representative in case of the children. Participants were either paid CHF 30 or received two cinema vouchers for taking part in the study.

Materials and procedure

The general structure of the PM task used in the study is portrayed in Figure 3. The task included 33 sequences that are composed of the formation of an intention, a varying number of ongoing activity trials, the externally prompted retrieval of the retrospective memory elements (= RM task), and a PM trial. The sequences comprise a total of 792 trials that were divided into two blocks and required approximately 25 minutes to complete without a break. More precisely, one sequence consists of: 1) an intention formation trial, 2) followed by six or ten ongoing activity trials, 3) that precede either the RM or PM trial, 4) again followed by six or ten ongoing activity trials, 5) with the subsequent presentation of either the RM or PM trial, and 6) three or five ongoing activity trials that conclude the sequence before a new intention is presented. The order of the RM and PM trials was randomized across sequences, as was the number of ongoing activity trials that were performed between the encoding and RM or PM trials. As an example, for the sequence portrayed in Figure 1 participants encode the intention to press the “c” key the next time a frame is magenta, they then respond to the externally prompted retrieval of RM elements (i.e., the retrieval of the context (i.e., color of the frame) and the intended action (i.e., letter “c”), thus the *intention content*), and then they encounter the PM cue (i.e., frame in magenta) and are supposed to self-initiate the appropriate prospective response (i.e., press “c”).

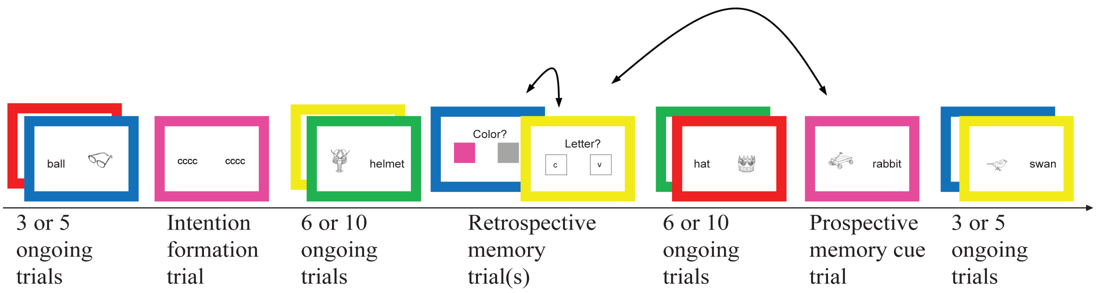

Figure 3. **An illustration of the prospective memory paradigm used in study 1 and 2 in this thesis.** Displayed is one of 33 analogue sequences consisting of an intention formation trial, a PM cue trial, and a RM cue trial (consisting of two subtasks) embedded in an ongoing activity. The order of appearance of RM cue trials and PM trials as well as the two subtasks within the RM cue trials are randomized between sequences, as indicated by the arrows.

Ongoing activity.

The ongoing activity was a semantic categorization task. For each trial one picture and one word in lowercase letters and black color were presented on the computer screen centered on the horizontal axis. Participants had to decide whether or not the picture and word belong to the same semantic category by pressing “n” with the right index finger for “yes” and “m” with the right middle finger for “no”. The picture-word pairs were surrounded by a colored frame in one of six different colors (i.e., blue, green, red, yellow, grey, or magenta) that was irrelevant to the ongoing activity.

PM task.

For *intention formation trials* two letter strings (“cccc cccc” or “vvvv vvvv”) were presented instead of a picture-word pair and the frame was either magenta or grey. Participants were asked to encode the combination of letter and frame color and to form the intention to press the key associated with the letter the next time the frame appeared in this color on an ongoing activity trial. To indicate that they had encoded the intention, participants pressed the corresponding key on the keyboard (“c” or “v”) with the left middle or index finger. There were four possible cue-intention pairs that were presented quasi-randomly across the task. For

PM trials the frame was presented in one of the two specific colors (i.e., grey or magenta) and participants were expected to press the key associated with the letter that was encoded on the intention formation trial. In order to correctly perform this task, participants not only needed to remember the specific combination of letter and frame color but also the intent itself that underlies the self-initiation of the action upon cue detection. In other words, the successful fulfilment of the PM task (=*PM hits*) needs the combination of both the RM elements and the purely prospective component of PM to be remembered and initiated correctly. As *PM miss* trial we counted those PM trials where the prospective cue was not detected and an ongoing activity response was made (“m” or “n”) instead of a PM response (“c” or “v”).

RM task.

The RM task consisted of two subtasks that were always presented consecutively. Each subtask prompted the indication of one part of the intention content for the most recently encoded intention, that is the color of the frame (i.e., grey or magenta which is the retrieval context) and the letter (i.e., “c” or “v” which is the intended action). The order of the color and letter probes was counterbalanced across PM sequences. For the color judgment, participants were presented with a square in grey and a square in magenta and asked to choose the color that was encoded for the most recent intention formation trial. For the letter judgment, the two letters were presented and participants indicated which of the two letters was encoded on the most recent intention formation trial. Participants indicated their choice by pressing “r” for the left position and “t” for the right position with the left middle and index finger. This task supplied four different variables: *RM letter* represented the total number of correctly remembered intended actions, *RM color* accordingly represented the total number of correctly remembered retrieval contexts. *RM hits* refer to those trials where both subtasks, that is the retrieval context and the intended action, were correctly remembered. *RM misses* reflect occasions where either the color or the letter or both of the intention content elements were not correctly remembered.

Participants were trained in two short blocks that could be repeated until the task was fully understood. The first training block followed the instruction for the ongoing activity and consisted of 20 semantic categorization trials. The second training block started after the instruction for the RM and PM tasks and consisted of three complete sequences that comprised 45 ongoing activity trials, three RM trials, and three PM trials. Participants were encouraged to ask questions during and after the training blocks to ensure that they understood the instructions before the experimental blocks began.

Stimuli.

The stimuli for the semantic categorization task were taken from a standardized set of 260 pictures of objects (simple black line drawings, Snodgrass & Vanderwart, 1980). Eighty-two pictures that belonged to ambiguous or unfavorable categories such as weapons or smoking utensils were excluded. The objects represented in the remaining 178 pictures were presented four times in the task, twice as a picture and twice as the associated word. Each object appeared twice in a related picture-word pair and twice in an unrelated picture-word pair. Hence, there were 712 ongoing tasks available. A fixed randomized list of ongoing activity trials (i.e., either six or ten) between the PM trials and the RM trials led to a total of 660 ongoing activity trials that was used for all participants.

The duration of stimulus presentation for the ongoing activity and PM trials was set to a minimum of 1600 ms and a maximum of 2800 ms. When participants responded after 1600 ms the next trial occurred after an inter-stimulus interval (ISI) of 250 ms. A response latency shorter than 1600 ms was filled with a blank screen until 1600 ms was reached, followed by the ISI. If participants did not answer after 2800 ms the ISI appeared and the next trial was presented. Presentation time for the intention formation and the RM trials was set to a minimum of 1600 ms. No maximum time was defined.

The response keyboard was prepared with a cover that left only the six keys visible that were used for the task. The keys were renamed and labeled accordingly to ensure clarity for participants. Here, however, the original labeling of the keys on the keyboard are given in order to allow replication of the task. In addition to behavioural data the electroencephalogram (EEG) continually recorded while participants performed the task. These neurophysiologic data are reported in Mattli, Zöllig, and West (2011).

Statistical analyses

Our first aim, namely, investigating age-related differences in the PM task and the two RM subtasks, was analyzed using a repeated-measures ANOVA with age group (young children, old children, young adults, middle-aged adults, young-old adults, old-old adults) as between-subject and condition (PM hits, RM letter, RM color) as within-subject factors. Significant main effects and interactions were further analyzed with planned pair-wise comparisons (i.e., Bonferroni) or (repeated) planned contrasts. The interaction resulting out of this analysis together with the analysis of what we called a *prospective component error rate* served to answer our second aim, which is the differential contribution of the two components as well as age-related differences. The prospective component error rate reflects instances in which a PM miss occurred although the complete intention content (i.e., letter and color) has been remembered correctly in the RM task of the same sequence. The total number of RM hits (= completely successful intention content retrieval trials) of each subject served as baseline for calculating the percentage of associated PM misses. The prospective component error rate was then analyzed in a one-way independent ANOVA followed by non-orthogonal (repeated) planned contrasts.

With respect to the third aim, analyzing age-related effects of intention content rehearsal on PM performance, we again used a repeated-measures ANOVA with order (RM task before, RM task after the PM task) and accuracy (RM hits, RM misses) as within-subject variables and age group as between-subject variable. For RM hits, the within-subject variables correspond to fields A and E in Table 2a and b. These fields reflect those situations where both the RM task and the PM task of a sequence were answered correctly. In regard of incorrect intention content rehearsal, the variables correspond to fields B and F (see Table 1a and 1b) which reflect those situations where one or both of the RM tasks were not answered correctly but the PM task was nonetheless executed correctly.

For all analyses the alpha level was set at .05 and effect sizes were reported as eta squared (η^2).

Table 2. **Schema of the current analyses.** Absolute and percentage mean scores within the six age groups for the four possible conditions when the prospective memory task (a) *precedes* or (b) *follows* the retrospective component task. For example: Field A represents the number of correctly answered prospective memory trials that were given *before* both of the retrospective subtasks were answered correctly too. The percentages add up vertically to 100% within each age group. YCh = young children, OCh = old children, YA = young adults, MaA = middle-aged adults YoA = young-old adults, OoA = old-old adults

(a)				Retrospective component task		
				hits		misses
Prospective memory task **before**	hit	YCh	A	5.37 (56.08%)	B	0.94 (27.35%)
		OCh		9.59 (82.61%)		0.76 (59.39%)
		YA		9.84 (81.18%)		0.11 (12.50%)
		MaA		8.93 (73.61%)		0.29 (40.63%)
		YoA		6.35 (56.19%)		0.41 (20.30%)
		OoA		2.19 (22.71%)		0.81 (12.17%)
	miss	YCh	C	3.87 (43.92%)	D	2.81 (72.65%)
		OCh		1.94 (17.39%)		0.71 (40.61%)
		YA		2.26 (18.82%)		0.79 (87.50%)
		MaA		3.07 (26.39%)		0.71 (59.37%)
		YoA		4.12 (43.81%)		2.12 (79.70%)
		OoA		5.38 (77.29%)		4.63 (87.83%)
				100%		100%

(b)				Retrospective component task		
				hits		misses
Prospective memory task **after**	hit	YCh	E	4.81 (32.06%)	F	0.94 (19.88%)
		OCh		10.71 (57.18%)		0.47 (40.90%)
		YA		10.79 (60.35%)		0.53 (19.87%)
		MaA		11.86 (62.83%)		0.07 (5.56%)
		YoA		7.29 (44.33%)		0.59 (21.42%)
		OoA		2.25 (15.87%)		0.25 (6.10%)
	miss	YCh	G	9.69 (67.94%)	H	4.56 (80.12%)
		OCh		8.06 (42.82%)		0.76 (59.10%)
		YA		7.11 (39.65%)		1.58 (80.13%)
		MaA		6.36 (37.17%)		1.71 (94.44%)
		YoA		9.00 (55.67%)		3.12 (78.58%)
		OoA		10.00 (84.13%)		7.50 (93.90%)
				100%		100%

3.1.3. Results

The 3 (condition: PM hits, RM letter, RM color) × 6 (age group) repeated-measures ANOVA revealed a significant main effects of condition, $F(2,186) = 303.18$, $p < .01$, $\eta^2 = .725$ and age group, $F(5,93) = 14.66$, $p < .01$, $\eta^2 = .441$. The pair-wise comparisons for the effect of condition revealed a significant difference between PM hits and both RM subtasks (both *p*s < .01), but a non-significant difference between RM letter and RM color ($p > .05$). The effect of age group reflected generally higher performance in old children compared to young children ($p < .01$). Old children, young, middle-aged and young-old adults did not differ in performance (all *p*s > .05), while old-old adults' performance was significantly lower than young-old adults' performance ($p < .01$). Most interestingly, the age group × condition interaction was significant, $F(10,186) = 4.36$, $p < .01$, $\eta^2 = .052$, indicating age-related differences in the performances of the PM and the RM tasks. Separate analyses for the PM task and the two RM subtasks to disentangle this significant interaction revealed the following: Performance in both RM subtasks significantly increased from young to old children ($p < .01$), did not differ in old children, young, middle-aged and young-old adults (all *p*s > .05), and significantly decreased from young-old to old-old adults ($p < .01$). PM task performance significantly increased from young to old children ($p < .01$), remained stable between old children, young and middle-aged adults (all *p*s > .05), and significantly decreased from middle-aged to young-old adults ($p < .05$) and from young-old to old-old adults ($p < .01$, see Figure 4). Thus, in contrast to the performance in the RM subtasks, young-old adults' performance was already reduced in the PM task compared to middle-aged adults'. This suggests that the prospective component of PM declines earlier than the retrospective component.

The one-way ANOVA analyzing the prospective component error rate revealed a significant main effect of age group, $F(5,99) = 10.69$, $p < .01$, $\eta^2 = .365$. The planned contrasts showed a U-shaped function reflecting a significant decrease from young to old children ($p < .01$), non-significant differences between old children, young and middle-aged adults (all *p*s > .05), and significant increases from middle-aged to young-old adults ($p < .05$) and from young-old to old-old adults ($p < .01$), respectively.

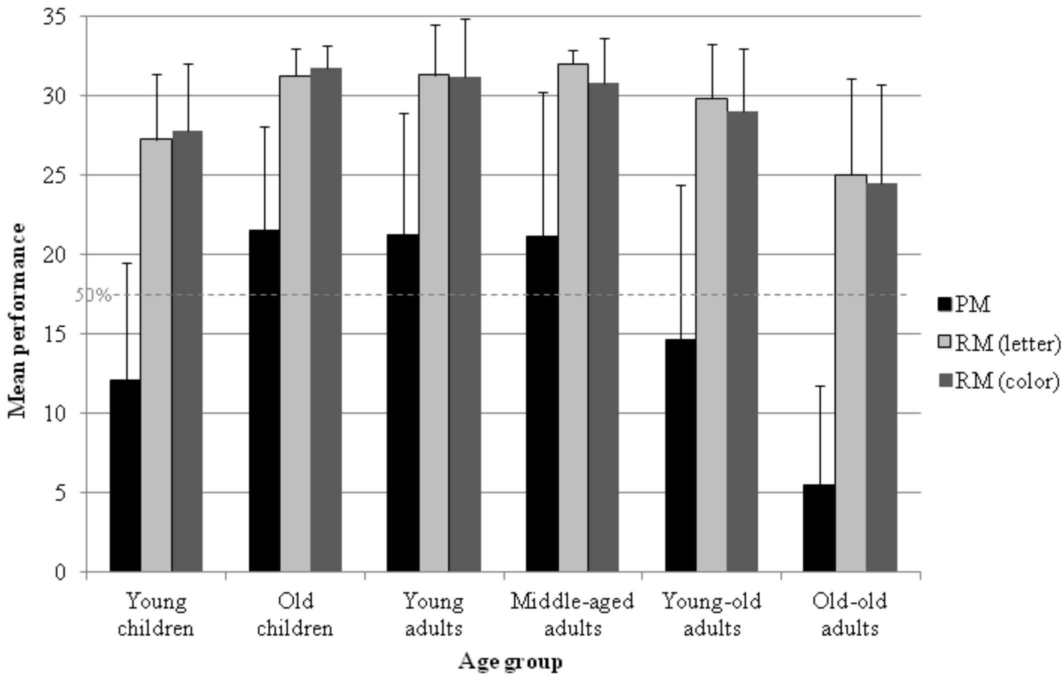

Figure 4. **Mean accuracy scores.** Mean accuracy for the prospective memory task (PM) and the two retrospective memory subtasks (RM letter and RM color) for the six age groups. The maximum score was 33 and the dashed line indicates the 50% mark.

The 2 (order: RM task before, RM task after the PM task) * 2 (RM accuracy: RM hit, RM miss) * 6 (age group) repeated-measures ANOVA with which potential rehearsal effects were examined, revealed a significant main effect of order, $F(1,57) = 37.27$, $p < .01$, $\eta^2 = .355$, reflecting that due to randomization there were more RM tasks after than before the PM task. However, this was the case in all age groups, $F < 2.15$, $p > .07$, $\eta^2 = .102$. The effect of age was significant, $F(5,57) = 7.05$, $p < .01$, $\eta^2 = .382$. The main effect of RM accuracy and the RM accuracy × age group interaction were also significant, $F(1,57) = 59.21$, $p < .01$, $\eta^2 = .429$ and $F(5,57) = 4.37$, $p < .01$, $\eta^2 = .158$, respectively, indicating that in all age groups there were more RM hits than RM misses and that the relative amount of RM hits varied across age groups. Most interestingly, neither the interaction of order × RM accuracy nor the triple interaction of order × RM accuracy × age group were significant, $F < 2.81$, $p > .09$, $\eta^2 = .040$ and $F < 2.0$, $p > .09$, $\eta^2 = .143$, respectively. This indicates that irrespective of the RM accuracy and the age group, there were more PM hits before the intention content rehearsal than after the intention content rehearsal. In other words a higher percentage of PM hits before RM hits were observed than after RM hits and a higher percentage of PM hits before RM misses than after, and both regardless of the participants' age.

3.1.4. Discussion

The main goals of this study were to analyze age-related differences in PM performance across the lifespan in a cross-sectional design including six age groups and to investigate possible mechanisms underlying differences in performance. More precisely, the contribution of retrospective memory processes and processes of the purely prospective component of the task were disentangled by experimentally controlling for RM performance. Furthermore, additional information on the role of RM processes in overall PM performance was gained by examining age-related effects of (correct or incorrect) rehearsal of the RM elements on PM performance.

Our data confirmed the inverted U-shaped function of PM performance across the lifespan. The performance in prospective remembering increased from younger to older childhood, whereas old children's PM performance was already as good as young adults' performance and stayed relatively stable in middle-aged adults. Our findings revealed that young-old adults already showed a reduced PM performance that further declined in old-old adults. The age-related performance differences in remembering the retrospective memory elements in our paradigm also mirrored an inverted U-shaped function. In both RM subtasks performance increased from young to old children and was then relatively stable and declined only in old-old adults. However, the level of performance between the PM and the RM tasks and its pattern across the lifespan were remarkably different: young children already performed the RM task on a high level with 83.4%[2] correct whereas the PM performance was on a much lower level (i.e., at a 36.6% correct). The same was observed for the other end of the lifespan whereas young-old adults reached 89.1% correct in the RM task but only 44.4% correct in the PM task. Old-old adults showed a further reduction in RM task performance (75.0% correct) and especially in PM hits (16.7% correct).

Based on these findings it was particularly interesting to disentangle the contribution of the RM component to the overall PM performance in each age group.

[2] Mean of RM letter and RM color, because they did not differ significantly.

To do this we computed a prospective component error rate in which we analyzed age-related differences in the proportion of missed PM responses despite correctly retrieved intention content in the RM task. Analyses revealed a U-shaped function of prospective component errors across the lifespan that seemed to match the findings of PM hit analyses in a mirror-inverted way. More precisely, we found a significant decrease of prospective component failures in old children as compared to young children, no change of prospective component failures between old children, young adults and middle-aged adults, a significant increase of failures between middle-aged adults and young-old adults, and another significant increase between young-old and old-old adults.

Taken together, our findings suggest that successful PM performance across the lifespan seems to be highly dependent on a functionally intact prospective component (i.e., the self-initiation of the PM response). The retrospective component of our task (i.e., remembering the intention content consisting of retrieval context and intended action) seems rather unproblematic for all age groups. Furthermore, analyses of accuracy indicated different developmental patterns of the two PM components across the lifespan. Functionality of both components seems to increase across childhood and to decrease from middle-aged adulthood to old age. However, the prospective component seems to decline earlier in life than the retrospective component and to even fall under the level of young children.

Theoretically, our findings can be linked to neuroanatomical studies looking at age-related structural changes of the brain (Giedd et al., 1999; Huttenlocher & Dabholkar, 1997; Jäncke, 2004; Raz et al., 2005; Sowell et al., 2003; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999). The prospective component is highly dependent on executive functioning that is often related to efficient frontal lobe functioning. The frontal lobes, or more specifically the prefrontal cortex (PFC), are known to mature relatively late, that is, not until adolescence, and to show relatively early signs of cerebral aging, that is, steady decline in adulthood (e.g., Huttenlocher & Dabholkar, 1997; Jäncke, 2004; Sowell et al., 1999; West, 1996). Accordingly, executive functions including the prospective component are not fully developed in children and already impaired in early old adulthood.

In contrast, the medial temporal lobes are reported to be fully developed in childhood, but show age-related decline beginning in the mid-fifties with an accelerated increase in the rate of decline towards very old age (e.g., Giedd et al., 1999; Raz et al., 2005). However, recognition performance (as in our retrospective component task) shows rather small developmental changes across the lifespan compared to free recall (Grady & Craik, 2000; Perlmutter & Lange, 1978; Zacks et al., 2000). Therefore, it appears reasonable to assume that the retrospective component of PM is fully functioning in old children, remains on a very high level across adulthood and shows no signs of decline until later adulthood (old-old adults).

Based on this discussion, the fact that old children performed as well as young adults in our PM task needs some further explanation given that in this age group executive functions are also reported to be not yet fully developed (e.g., planning, monitoring, De Luca et al., 2003) as compared to young adults. In our study, old children assumedly engaged in compensatory mechanisms to counteract their reported difficulties in executive function. It seems plausible that other brain regions besides the prefrontal cortex were recruited to ensure successful performance (Zöllig & Eschen, 2009). Hence, future research should examine if this same behavioral outcome of old children and young adults was indeed based on different neural correlates. A possible example for such compensatory neural activity in old children might be secondary visual areas (i.e., cuneus, precuneus), which have been reported in previous findings and functionally been associated with visual imagery and surface processing (Zöllig & Eschen, 2009; Zöllig et al., 2010; Zöllig et al., 2007). Future research combining a lifespan approach with imaging data could shed some light on these possible compensatory mechanisms. Cognitively, one possible mechanism might be that old children benefited from their flexible visual attention despite their relative inability to focus attention on one task (Strutt, Anderson, & Well, 1975). In our paradigm this could mean that the focus was not fixed on the ongoing task, but rather that their attention switched between tasks, which might have led to more automatic cue detection.

To further define the role of the retrospective component to PM performance we examined if and how PM performance in the different age groups was affected by the rehearsal of the intention content of the respective sequence. On the one hand, we hypothesized that the correct recall of the intention content before the PM trial might serve as a reminder of the to-be executed PM task and thereby boost PM performance. On the other hand, we hypothesized that the incorrect recall of the intention content before the PM trial might hinder the correct execution of the PM task, reflecting an intrusion effect (Shindler, Caplan, & Hier, 1984). Our results revealed lower performance in the PM task after correct and incorrect intention content retrieval for all age groups.

This somewhat surprising and hypothesis-countering result with respect to the correct intention content retrieval and still lower subsequent PM performance certainly needs to be analyzed further. One potential explanation might lie in the idea of a tension-system created through the intention formation (Goschke & Kuhl, 1996; Lewin, 1926). Following this idea, the tension gets released when the intention is fulfilled. Accordingly, one could speculate that once participants answered the RM task (irrespective of accuracy) the tension was released because part of the intention, namely its content, was executed. As a consequence, accuracy in the following PM trial was lowered. However, this tension hypothesis clearly calls for future studies and the development of appropriate paradigms.

Limitations

In the present study all age groups were examined with exactly the same paradigm. A relatively easy semantic ongoing activity was chosen, aiming for comparable task difficulty levels in all age groups. However, specifically for young children who were only in their second or third year of primary school, the semantic categorization task could have been more difficult than for adults due to slower reading ability. Moreover, different semantic categories might be used across the lifespan. To overcome this problem, participants were explicitly told that there was no right or wrong response for the ongoing activity tasks and were encouraged to guess if necessary. We assume that even if reading ability and the semantic categories had differed across age groups, this would have almost no effect on the PM performance in our task. Moreover, statistical analysis of reaction times in ongoing activity trials, which indicate the effort to complete the ongoing activity task, showed no significant correlation with correct PM trials in either age group. Thus, we would argue that our paradigm is adequate to measure PM performance across the lifespan.

In addition, this study examined only one aspect of PM performance, namely purely cognitive variables. However, as stated by Banville and Nolin (2000), only 23% of the variance in PM performance can be explained by factors called “general mnestics” and executive functions, whereas the rest (77%) of the variance relies on multiple dimensions such as other cognitive functions, personal, social, and environmental factors. Therefore, future studies should aim at exploring the relative contribution of the PM components across the lifespan under the influence of differential factors.

Conclusion

This study was designed to gain a more detailed understanding of the development of PM across the lifespan. By including six age groups into the study sample, we affirmed the proposed inverted U-shaped function of PM performance across the lifespan and found a paradigm with which we could assess performance across the lifespan. The separate measurement of PM performance and its retrospective memory elements allowed further insights into differential effects of increasing age on the two PM components.

Based on our data, we conclude that it is mainly the prospective part of a PM task that leads to declined PM performance in young children and old adults. Moreover, our findings suggest that the relative contributions of the prospective and retrospective components to PM performance are not uniform at both ends of the lifespan. In fact, it seems that in later adulthood the prospective component determines performance to an even greater extent than in childhood.

3.2. Study II: Age-related differences in the temporal dynamics of prospective memory retrieval: A lifespan approach[3]

3.2.1. Introduction

The ability to form, retain and later execute an intention without an explicit external agent that prompts a memory search when the retrieval context occurs, constitutes *prospective memory* (PM, Brandimonte et al., 1996; Kliegel, McDaniel et al., 2008). Successful PM is supported by two fundamentally different components (i.e., retrospective and prospective, Einstein et al., 1992; Einstein & McDaniel, 1990, 1996; Kliegel, Mackinlay et al., 2008; Martin, Kliegel, & McDaniel, 2003). The retrospective component allows the individual to retrieve the content of the intention (i.e., retrieval context and intended action) from memory when a relevant cue is encountered in the environment (Einstein & McDaniel, 1996). There is significant overlap between the processes contributing to the retrospective component of PM and those contributing to other forms of explicit episodic memory (Einstein & McDaniel, 1996; West & Krompinger, 2005). The processes underlying the prospective component are more closely aligned with executive control and support the detection of PM cues in the environment, the coordination of the ongoing activity and execution of the intended action, and monitor the outcome of an action (Marsh et al., 2002; West, 2011). Studies examining the development of PM reveal an inverted U-shaped distribution in the efficiency of PM across the lifespan, with PM improving from childhood to young adulthood and then declining from young adulthood to later adulthood (Kliegel, Mackinlay et al., 2008; Zimmermann & Meier, 2006; Zöllig et al., 2007). Evidence from behavioral and electrophysiological levels of analyses lead to the suggestion that somewhat different processes may contribute to the development of PM across the lifespan (Zöllig et al., 2007). The current study examined age-related differences in the neural correlates of PM in individuals 7.5 to 83 years of age to determine whether similar or distinct processes contribute to variation in PM across the lifespan.

[3] A similar version of this chapter has been published as "Mattli, F., Zöllig, J., & West, R. (2011). Age-related differences in the temporal dynamics of prospective memory retrieval: A lifespan approach. *Neuropsychologia, 49*, 3494-3504."

The development of PM

The success of PM typically increases from young childhood to about the mid-twenties (e.g., Ceci et al., 1988; Guajardo & Best, 2000; Kliegel & Jäger, 2007; Kvavilashvili et al., 2001; Martin & Kliegel, 2003; R. E. Smith et al., 2010) and then starts to decline in middle adulthood (Maylor & Logie, 2010) with an acceleration of decline in later adulthood (Kliegel & Jäger, 2006). There is some debate regarding whether age-related differences in PM across the lifespan result from variation in the efficiency of the prospective or retrospective component of PM. Some investigators have argued that the development of executive control processes associated with the prospective component (e.g., strategic monitoring of the environment) represents the primary locus for improvement in PM between 7 and 12 years of age (Ceci et al., 1988; Kerns, 2000; Zimmermann & Meier, 2006). In contrast, Smith et al. (2010) provide evidence demonstrating that processes associated with the retrospective component may represent the critical factor in understanding the development of PM from childhood to young adulthood. Consistent with this view, Zöllig et al. (2007) found that the development of PM between adolescence and young adulthood reflected a reduction in both the number of confusion errors for PM cues and false alarms for PM lures. Both types of errors could be considered indices of the retrospective component, since for each the content of the intention (i.e., the intended action in confusions and the retrieval context in false alarms) does not appear to be remembered correctly (West & Craik, 1999, 2001; Zöllig et al., 2007). Alternatively, false alarms to PM lures could also result from inefficient executive control processes that give rise to impulsive PM responses before the appropriate response is retrieved from memory. Zöllig et al. also found non-significant differences in the number of prospective misses between adolescents and younger adults, indicating that the efficiency of the prospective component may be similar at these two points of development.

Work examining the nature of age-related differences in PM between younger and older adults also reveals inconsistencies across studies. Some evidence indicates that aging has a stronger effect on processes associated with the prospective component than the retrospective component of PM (A. L. Cohen, West, & Craik, 2001; R. E. Smith & Bayen, 2004; West & Craik, 2001). Furthermore, other evidence indicates that this effect may result from a decrease in the efficiency of preparatory attentional processes that facilitate the detection of PM cues in older adults (R. E. Smith & Bayen, 2004). In contrast, other findings reveal that aging can be associated with a decline in processes associated with the retrospective component of PM (Einstein et al., 1992; Zimmermann & Meier, 2006). As an example, Zöllig et al. (2007) reported an increase in PM confusion errors and false alarms to PM lures in older adults relative to younger adults. Both of these types of errors could be attributed to failures of the retrospective component of PM; although, as noted above false alarms to PM lures might also result from impulsive responses associated with inefficient executive control processes.

The ERP correlates of PM and development

Studies using event-related brain potentials (ERPs) to investigate the neural correlates of PM have revealed ERPs that are associated with the prospective and retrospective components of PM. The prospective component is associated with processes related to the detection of PM cues (N300), switching from the ongoing activity to the prospective response (frontal positivity), and configuration of the prospective task set (prospective positivity); and the retrospective component is associated with processes related to retrieval of an intention from memory (parietal old-new effect, for a review see West, 2011). These studies have also revealed sustained neural activity over the frontal and parietal regions of the scalp that are associated with strategic monitoring of the environment for a PM cue (West, 2007; West, McNerney, & Travers, 2007). The effects of development from adolescence to young adulthood on some of these ERP components have been examined in a study by Zöllig et al. (2007), and the effects of aging have also been considered in a small number of studies (West & Bowry, 2005; West & Covell, 2001; West, Herndon, & Covell, 2003; Zöllig et al., 2007).

The N300 reflects greater negativity for PM cues than ongoing activity trials over the occipital-parietal region of the scalp between 300-500 ms after stimulus onset (West, 2007; West, Herndon, & Crewdson, 2001). The amplitude of the N300 is greater for PM hits than for PM misses and ongoing activity trials, and may be similar for PM misses and ongoing activity trials (West, 2007; West & Krompinger, 2005; West & Ross-Munroe, 2002). These findings have led to the suggestion that the N300 is associated with the detection of an event-based PM cue in the environment. Evidence from three studies reveals that the amplitude of the N300 is attenuated in older adults (West & Bowry, 2005; West & Covell, 2001; West, Herndon et al., 2003). Some evidence indicates that the effect of age on the N300 may result from the reduction in the efficiency of executive processes that facilitate the detection of PM cues (West & Bowry, 2005); although, it is also possible that differential task-related recruitment in younger and older adults or greater within person variability in the timing of the ERPs between older than younger adults also contributes to this effect. In contrast, other data reveals that there may be relatively little effect of age upon the amplitude of the N300 from adolescence to later adulthood (Zöllig et al., 2007). The failure to find age-related differences in the amplitude of the N300 by Zöllig et al. appears to be related to differential neural recruitment early and later in life that may obscure developmental trends in the N300 when measures of mean voltage are considered.

The frontal positivity reflects greater positivity for PM cues than for ongoing activity trials over the midline frontal region of the scalp between 300-500 ms after stimulus onset (West, 2007, 2011). Like the N300, the frontal positivity distinguishes between PM hits and PM misses and ongoing activity trials (West, 2007). Based upon similarities between the frontal positivity and components of the ERPs related to task switching, some investigators have proposed that the frontal positivity is associated with an executive control process that supports switching between the ongoing and prospective elements of the task (Bisiacchi, Schiff, Ciccola, & Kliegel, 2009; West, 2011). The amplitude of the frontal positivity may be attenuated in older adults relative to younger adults (West, Herndon et al., 2003), and the effect of development from childhood to young adulthood on the frontal positivity has not been investigated.

Beginning around 400 ms after stimulus onset, PM cues are associated with a sustained positivity over the parietal region of the scalp relative to ongoing activity trials (West et al., 2001). The parietal positivity represents three distinct components of the ERPs. The P3b contributes to the parietal positivity (West & Wymbs, 2004). The influence of the P3b on the parietal positivity can be minimized by using PM cues that are perceptually similar to the ongoing activity stimuli (West, Wymbs et al., 2003). The recognition old-new effect also contributes to the parietal positivity and is associated with the retrieval of an intention from memory (i.e., the retrospective component of PM, West & Krompinger, 2005). The third component that contributes to the parietal positivity is the prospective positivity (West & Krompinger, 2005).

The prospective positivity tends to emerge later than the P3b (West, Wymbs et al., 2003) or the old-new effect (West, 2007), and may be associated with an executive control process that supports configuration of the prospective task set (Bisiacchi et al., 2009; West, 2011). The amplitude of the parietal positivity decreases from adolescence to younger adulthood to later adulthood (West & Bowry, 2005; West & Covell, 2001; Zöllig et al., 2007). This finding indicates that there is age-related variation in the amplitude of ERP components that contribute to the parietal positivity. Based upon available evidence it is difficult to determine which of the three components contributes to age-related differences in the parietal positivity from childhood to young adulthood; in contrast, in older adults it appears that age-related reduction in the amplitude of the P3b (West & Covell, 2001) and prospective positivity (West & Bowry, 2005) contribute to the age-related effect on the parietal positivity.

The ERP correlates of strategic monitoring have been examined in a small number of studies comparing neural activity elicited on ongoing activity trials preceding PM trials (i.e., when individuals should be monitoring for these stimuli) and following PM hits (i.e., after the intention was realized and it was no longer necessary to monitor for the cue, West et al., 2007), and on ongoing activity trials for PM and no-PM conditions (West & Bowry, 2005; West, Bowry, & Krompinger, 2006). In these studies, strategic monitoring is commonly associated with slow wave activity over the frontal and parietal regions of the scalp that distinguishes ongoing activity trials preceding PM cues from ongoing activity trials following PM cues, and PM trials from no-PM trials, respectively. The modulation begins around 200-400 ms after stimulus onset and lasts for several hundred milliseconds. The amplitude of this slow wave activity may decrease as the working memory demands of the ongoing activity increase (West et al., 2006), consistent with the idea that strategic monitoring requires the allocation of controlled attentional resources (R. E. Smith, 2003). The effects of aging on the neural correlates of strategic monitoring have been examined in one study (West & Bowry, 2005). In this study, slow wave activity related to strategic monitoring was observed in younger and older adults, and there appeared to be some age-related differences in the time course and topography of this neural activity.

The current study

As described above, the purpose of the current study was to examine the neural correlates of PM in a lifespan sample ranging in age from 7.5 to 83 years. The study utilized a modification of the PM encoding-retrieval paradigm (West & Ross-Munroe, 2002; Zöllig et al., 2007) that allowed us to obtain ERPs for ongoing activity trials, PM cue trials that elicited a correct prospective response (PM hits), PM cue trials that failed to elicit a prospective response (PM misses), and successful recognition memory of the elements of the intention (RM hits). The paradigm also allowed us to examine components of the ERPs related to strategic monitoring by comparing ongoing activity trials preceding PM trials when individuals should be monitoring for PM cues – and following PM hits – when it was no longer relevant to monitoring for PM cues.

We examined several predictions related to the potential basis of age-related differences in PM across the lifespan. If the developmental trajectory of PM across the lifespan results from variation in the efficiency of processes that facilitate the detection of PM cue or switching from the ongoing activity (West & Bowry, 2005; Zöllig et al., 2007), then there should be age-related differences in the N300 and/or frontal positivity. Also, if processes contributing to the retrospective component contribute to the development of PM (R. E. Smith et al., 2010), then there should be age-related difference in the parietal positivity or other neural activity that distinguishes PM hits and RM hits from ongoing activity trials. Finally, if the development of PM is associated with variation in strategic monitoring across the lifespan (R. E. Smith & Bayen, 2004; R. E. Smith et al., 2010), there should be age-related differences in slow wave activity associated with monitoring.

3.2.2. Methods

Participants

The sample included 105 individuals' aged 7.5 to 83 years that were divided into 3 age groups: children (N = 33 (14 f), M = 10.3 years, SD = 1.7), younger adults (N = 33 (18 f), M = 31.4 years, SD = 8.4), and older adults (N = 33 (11 f), M = 68.2 years, SD = 8.2). All participants were in good health and none reported brain injuries, psycho-affective medication, drug consumption or diseases affecting brain functioning. All participants were native German speakers. A standard psychometric battery was used to screen for participants scoring more than one standard deviation below age appropriate norms on verbal intelligence, psychomotor speed, memory span and planning ability. The data for six participants were excluded due to technical problems (1 child and 3 younger adults), poor performance on the psychometric battery (1 older adult), or difficulties in color discrimination (1 older adult); resulting in data for 99 participants being included in the analyses.

Children were recruited at school either by their teachers or through the distribution of flyers that were approved by the school authority. Younger adults were recruited through placards on a notice board at the University of Zurich and at centers for continuing education around Zurich. Older adults were recruited at a lecture for senior citizens at the University of Zurich. The experiments were conducted in agreement with the declaration of Helsinki. Informed consent was obtained from all participants or their lawful representative in case of the children. Participants were either paid 30 CHF or received two cinema vouchers.

Materials and procedure

The general structure of the prospective memory task used in the study is portrayed in Figure 3. The task included 33 intention encoding, ongoing activity, and retrospective and prospective memory retrieval sequences that were presented in 792 total trials that were divided into two blocks and required approximately 25 minutes to complete without a break. Each sequence consisted of: 1) an intention formation trial, 2) six or ten ongoing activity trials, 3) the RM or PM cue trials, 4) six or ten ongoing activity trials, 5) the RM or PM cue trials, and 6) three or five ongoing activity trials. The order of the RM and PM cue trials was randomized across sequences, as was the number of ongoing activity trials that were performed between the encoding and RM or PM cue trials. As an example, for the sequence portrayed in Figure 3 participants encode the intention to press the “c” key the next time a frame is magenta, then respond to the RM cues (i.e., retrieval of the color of the frame and then the action), participants then encounter the PM cue (i.e., frame in magenta) and make the prospective response (i.e., press “c”).

Ongoing activity.

The ongoing activity was a semantic categorization task. For each trial one picture and one word, in lowercase letters and black color, were presented on the computer screen centered on the horizontal axis. Participants had to decide whether or not the picture and word belong to the same semantic category by pressing "n" with the right index finger for "yes" and "m" with the right middle finger for "no". The picture-word pairs were surrounded by a colored frame in one of six different colors (i.e., blue, green, red, yellow, grey, or magenta) that was irrelevant to the ongoing activity.

PM task.

For *intention formation trials* two letter strings ("cccc cccc" or "vvvv vvvv") were presented instead of a picture-word pair and the frame was either magenta or grey. Participants were asked to encode the combination of letter and frame color and to form the intention to press the key associated with the letter the next time the frame appeared in this color on an ongoing activity trial. To indicate that they had encoded the intention, participants pressed the corresponding key on the keyboard ("c" or "v") with the left middle or index finger. There were four possible cue-intention pairs that were presented quasi-randomly across the task. For *PM cue trials* the frame was presented in one of the two PM colors (i.e., grey or magenta) and participants were expected to press the key associated with the letter that was encoded on the intention formation trial. A *PM hit* represented pressing the appropriate key for the trial where the relevant frame was presented. As *PM miss* trials we counted those PM cue trials where the prospective cue was not detected, that is an ongoing activity response was made ("m" or "n") instead of a PM response ("c" or "v"). Other errors, that is *confusion errors* (i.e., PM cues that elicited the wrong PM response that is "c" instead of "v" or vice versa), *PM time outs* (i.e., PM cues that did not elicit any response), and *false alarms* (i.e., ongoing activity trials that elicited a prospective response) were not analyzed because of too low signal-to-noise ratios resulting from too few trials (see Table 3).

Table 3. **Mean accuracy scores.** Mean (*M*) accuracy for children (Ch), younger adults (YA), and older adults (OA) for PM hits, PM misses, confusion errors, PM time outs, and false alarms. The maximum score was 33.

		Age group		
		Ch	YA	OA
PM hits	*M (SD)*	16.9 (8.4)	21.2 (8.1)	10.3 (9.3)
PM misses	*M (SD)*	11.2 (7.9)	8.6 (7.0)	16.5 (9.3)
Confusion errors	*M (SD)*	1.9 (1.8)	1.3 (2.7)	0.9 (1.3)
PM time outs	*M (SD)*	3.0 (2.6)	1.9 (1.9)	5.3 (4.4)
False alarms	*M (SD)*	1.6 (1.7)	0.4 (0.9)	2.6 (3.1)

RM task.

For the RM cue trials individuals were asked to indicate the color of the frame (i.e., grey or magenta) and the letter (i.e., c or v) for the most recently encoded intention. The order of the color and letter probes was counterbalanced across PM sequences. For the color judgment, participants were presented with a grey square and a magenta square and asked to choose the color that was encoded for the most recent intention formation trial. For the letter judgment, the two PM cue letters were presented and participants indicate which of the two letters was encoded on the most recent intention formation trial. Participants indicated their choice by pressing the “r” for the left position or the “t” key for the right position with the left middle and index finger.

Participants were trained in two short blocks that could be repeated until the task was fully understood. The first block followed the instruction for the ongoing activity and consisted of 20 semantic categorization trials. The second block started after the instruction for the PM task and consisted of 45 ongoing activity trials, three PM tasks, and three by two RM cue trials. Participants were encouraged to ask questions during and after the practice blocks to ensure that they understood the instructions before the experimental blocks began.

Stimuli.

The stimuli for the semantic categorization task were taken from a standardized set of 260 pictures of objects (simple black line drawings, Snodgrass & Vanderwart, 1980). Eighty-two pictures were excluded that belonged to ambiguous or unfavorable categories such as weapons or smoking utensils. The objects represented in the remaining 178 pictures were presented four times in the task, twice as a picture and twice as the associated word. Each object appeared twice in a related picture-word pair and twice in an unrelated picture-word pair. Hence, there were 712 ongoing tasks available. A fixed randomized list of ongoing activity trials (i.e., either six or ten) between the PM cue trials and the RM cue trials led to a total of 660 ongoing activity trials that was used for all participants.

The duration of stimulus presentation for the ongoing activity and PM cue trials was set to a minimum of 1600 ms and a maximum of 2800 ms. When participants responded after 1600 ms the next trial occurred after an inter-stimulus interval (ISI) of 250 ms. A response latency shorter than 1600 ms was filled with a blank screen until 1600 ms was reached, followed by the ISI. If participants did not answer after 2800 ms the ISI appeared and the next trial was presented. Presentation time for the intention formation and the RM cue trials was set to a minimum of 1600 ms. No maximum time was defined.

The response keyboard was prepared with a cover that left only the six keys visible that were used for the task. The keys were renamed and labeled accordingly to ensure clarity for participants. Here, however, the original keys on the keyboard are given in order to allow replication of the task.

Recording and processing of electrophysiological data

Recording.

The EEG was recorded at 500 Hz with a DC QuickAmp amplifier (DC-1000 Hz; Brain Products GmbH) and a 22 bit A/D converter (Vision Recorder, Brain Products GmbH) from 40 unipolar Ag/AgCl-scalp electrodes placed – according to the 10-20 system (Jasper, 1958) – with an EasyCap (FMS Falk Minow Services, Easycap GmbH) and two bipolar Ag/AgCl-electrodes to record vertical and horizontal eye movements. During recording an inter-electrode impedance of below 10kΩ, and no filter was applied. An average reference was used.

Processing.

The Vision Analyzer 2 software (Brain Products GmbH) was used for offline processing of the EEG. All electrodes were still referenced to an average reference. The data were bandpass-filtered (0.1 Hz – 12 Hz, time constant 1.5915, 24 dB/oct). Independent component analysis (ICA) was used to correct muscular and ocular artifacts. Uncorrected artifacts were eliminated by manual inspection of the data comparing the ocular components, the timing and topographical distribution of the artifacts against that of the independent components. Finally, the semiautomatic Raw Data Inspector (Vision Analyzer 2 software, Brain Products GmbH) was applied to reject residual artifacts.

ERPs were then averaged for five types of trials: *Ongoing activity trials that immediately preceded PM cues* (children: $M = 32.27$, $S.D. = 1.27$; younger adults: $M = 32.36$, $S.D. = 0.98$; older adults: $M = 32.67$, $S.D. = 0.54$), *Ongoing activity trials that followed PM hits* (children: $M = 16.80$, $S.D. = 6.95$; younger adults: $M = 21.23$, $S.D. = 8.33$; older adults: $M = 10.07$, $S.D. = 7.96$), *PM hits* (children: $M = 16.58$, $S.D. = 6.82$; younger adults: $M = 21.04$, $S.D. = 8.29$; older adults: $M = 9.89$, $S.D. = 7.78$), *PM misses* (children: $M = 10.97$, $S.D. = 7.29$; younger adults: $M = 8.46$, $S.D. = 7.08$; older adults: $M = 16.46$, $S.D. = 8.65$), and *RM hits* collapsed across the two judgments (children: $M = 59.94$, $S.D. = 4.56$; younger adults: $M = 62.80$, $S.D. = 3.87$; older adults: $M = 56.15$, $S.D. = 7.42$). The stimulus-locked ERP epoch included a 200 ms prestimulus baseline and 1200 ms of poststimulus activity.

Statistical analyses

Behavioral data.

PM hits were analyzed in a one-way independent ANOVA and to further analyze differences across the three age groups, we performed non-orthogonal (repeated) planned contrasts, comparing younger adults to children and older adults to younger adults.

Mean amplitude.

Mean differences in ERP amplitude between trials and groups were analyzed using repeated-measures ANOVA. The selection of epoch and electrodes for the analyses was guided by the findings of previous research (e.g., West et al., 2001; West & Krompinger, 2005; Zöllig et al., 2007). The amplitude of the N300 was measured as mean amplitude between 270-350 ms after stimulus onset, and included data for four electrodes (PO3, PO4, O1, O2), two on each hemisphere. For the analyses, electrodes within one hemisphere were collapsed to get a mean activity. The amplitude of the frontal positivity was measured as mean activity between 350-400 ms and included electrodes F1, F2, F3 and F4. Again, electrodes within one hemisphere were collapsed to get a mean activity. Finally, the amplitude of the parietal positivity was measured as mean amplitude between 600-800 ms, and the analyses included data of electrodes P3, P4, CP3 and CP4, whereas electrodes within one hemisphere were again collapsed to get a mean activity. The analyses included data for three types of trials: ongoing activity preceding PM cues, PM hits, and PM misses. Post hoc Tukey tests qualified the results in case of a significant main effect of age. The Greenhouse-Geisser corrected degrees of freedom were applied if sphericity could not be assumed. Significant interactions of age × trial were decomposed in two contrasts: First, we compared the amplitude for ongoing activity trials to the amplitude for PM hits to establish the presence of the relevant component in each group. Second, we compared the amplitude for PM hits and PM misses to determine whether or not the component discriminated between realized and unrealized intentions within the groups.

Spatiotemporal analysis

Partial least squares (PLS) analysis.

PLS analysis was applied to an ERP data matrix representing the data for groups, subjects and conditions in the rows, and the amplitudes for time points between 0-1200 ms at 40 channels in the columns. The input (deviation) matrix for the PLS analysis was obtained by mean-centering the columns of the data matrix with respect to the grand mean. Singular value decomposition (SVD) was performed on the deviation matrix to identify the structure of the latent variables. Three outputs were obtained from the SVD that were used to interpret the relationships between ERP amplitude, task design, and age group. The first was a vector of singular values that are similar to eigenvalues and represent the unweighted magnitude of each latent variable. The singular values were used to calculate the percentage of task-related variance attributable to each latent variable. The second and third outputs represent the structure of the latent variables and are orthogonal pairs of vectors (saliences) that are similar to component loadings in PCA. One vector defines the weighted contrasts among conditions (*brain scores*) and the other vector represents the *electrode saliences* that reflect the spatial-temporal distribution of the latent variable across the scalp. The electrode saliences reflect components or modulations of the ERP waveforms that differ in amplitude across task conditions (e.g., an effect on the N300 might reflect stable saliences over the occipital-parietal region of the scalp between 200-400 ms).

The significance of the latent variables' singular values was determined using a permutation test (200 replications) that provided an exact probability of observing the latent variable's singular value by chance (e.g., p = .01); the stability of the electrode saliences at each time point and location on the scalp and the brain scores for the task conditions was established through bootstrap resampling (200 replications) that provides a standard error for each of the electrode saliences and brain scores. The ratio of the salience to its bootstrapped standard error is approximately equivalent to a z-score; therefore, bootstrap ratios greater than 3.0 can be taken to indicate saliences that differ from zero at the p < .001 level. Matlab code to perform the PLS analyses can be obtained at (http://www.rotman-baycrest.on.ca).

3.2.3. Results

Behavioral results

The one-way independent ANOVA for correctly answered prospective memory trials revealed a significant effect of age, $F(2,96) = 13.25$, $p < .01$, $\eta^2 = .216$. The planned contrasts revealed a significant increase in performance from children to younger adults ($p < .05$) and a significant decrease from younger to older adults ($p < .01$).

Differences in mean amplitude

The grand-averaged ERPs at twelve electrodes portraying the N300, frontal positivity and parietal positivity for the three age groups are presented in Figure 5.

N300.

The *N300* was analyzed in a 3 (age: children, younger adults, older adults) × 3 (trial: PM hits, PM misses, ongoing activity trials) × 2 (hemisphere: left (PO3-O1), right (PO4-O2)) repeated-measures ANOVA. The main effect of trial was significant, $F(2,178) = 5.56$, $p < .01$, $\eta^2 = .064$, $\varepsilon = .76$ (see Figure 5), with amplitude becoming more negative from ongoing activity trials to PM misses ($p < .05$) to PM hits ($p < .01$). The main effect of age, $F(2,89) = 31.61$, $p < .01$, $\eta^2 = .415$, and the age × trial interaction were also significant, $F(4,178) = 5.56$ ($\varepsilon = .80$), $p < .01$, $\eta^2 = .104$. Post hoc Tukey tests revealed a significant decrease in amplitude from children to younger adults ($p < .01$), and no difference between the younger and older adults ($p > .10$).

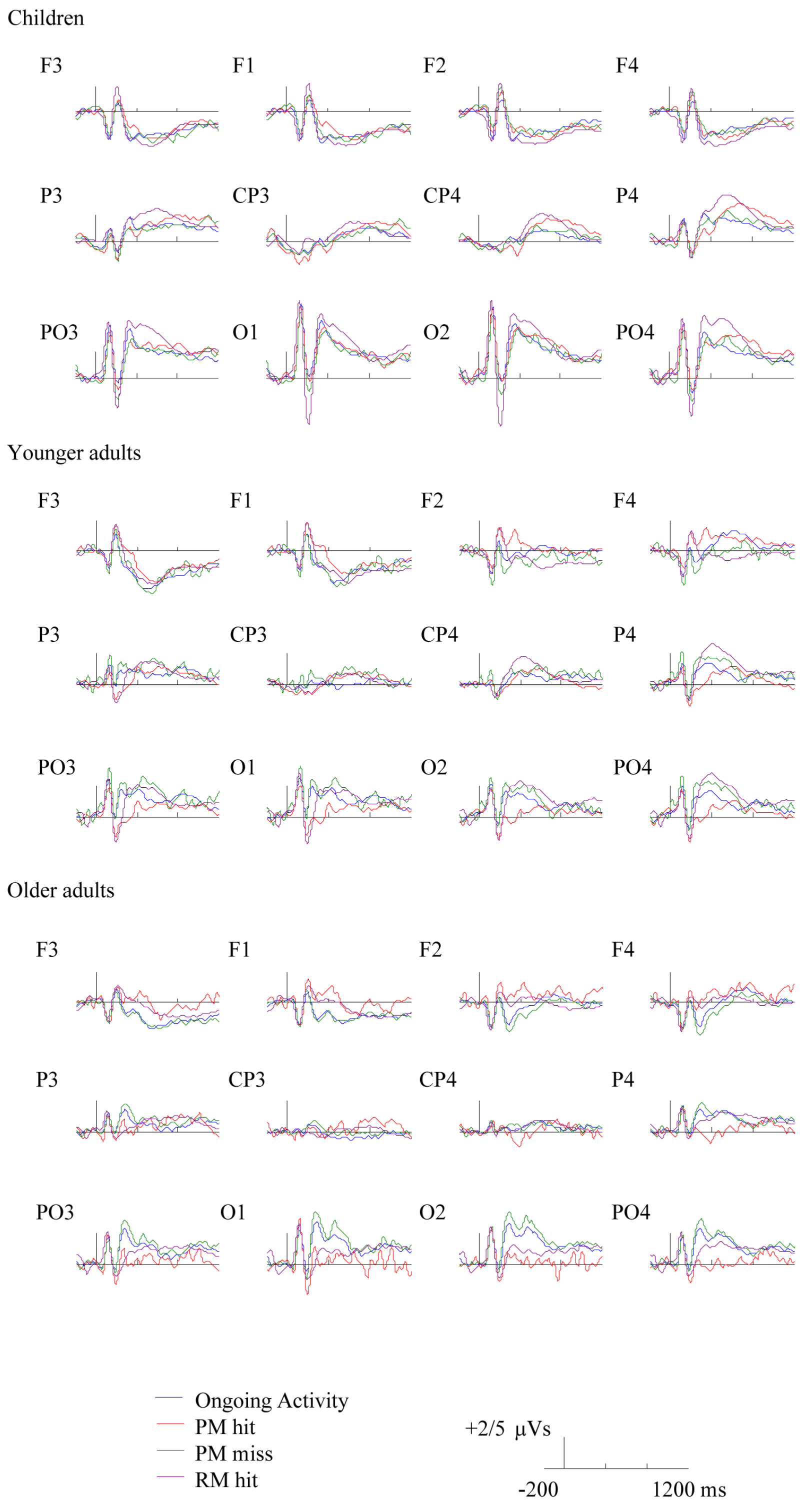

Figure 5. **Grand-averaged event-related brain potentials at 12 electrodes used in the ANOVAs.** They demonstrate the N300 (PO3, O1, O2 and PO4), the frontal positivity (F3, F1, F2 and F4) and the parietal positivity (P3, CP3, CP4 and P4) for ongoing activity trials, PM hits, PM misses, and RM hits in children, younger adults, and older adults. The tall bar presents stimulus onset and 5 µVs in the children and 2 µVs in the adults to reflect the dramatic difference in amplitude between the children and adults; and the short bars represent 400 ms increments.

For the contrast comparing ongoing activity trials to PM hits, the main effect of trial was significant, $F(1,92) = 19.48$, $p < .01$, $\eta^2 = .175$, and the age × trial interaction was not significant, $F < .005$, $\eta^2 < .001$ (Figure 6). These findings indicate that the amplitude of the N300 differentiating PM hits from ongoing activity trials was similar across the three age groups. For the contrast comparing PM hits to PM misses, the main effect of trial was not significant, $F < 2.34$, $\eta^2 = .023$, however, the age × trial interaction was significant, $F(2,89) = 5.48$, $p < .01$, $\eta^2 = .107$. The interaction reflected the fact that the amplitude of the N300 was greater for PM hits than for PM misses in the younger and older adults (*p*s < .01), but not in the children ($p > .10$). These results lead to the suggestion that in younger and older adults the failure to detect the PM cues was associated with failures to realize the intention (West & Ross-Munroe, 2002). In contrast, in children the amplitude of the N300 was similar for PM hits and PM misses leading to the suggestion that cue detection was not necessarily associated with realization of the intention in childhood.

Frontal positivity.

The amplitude of the *frontal positivity* was analyzed in a 3 (age) × 3 (trial: PM hits, PM misses, ongoing activity trials) × 2 (hemisphere: left (F1-F3), right (F2-F4)) repeated-measures ANOVA. The main effects of trial, $F(2,178) = 5.59$ ($\varepsilon = .64$), $p < .05$, $\eta^2 = .059$, and of age, $F(2,89) = 43.94$, $p < .01$, $\eta^2 = .492$, were significant. Post hoc tests revealed significant differences between PM hits and ongoing activity trials ($p < .01$), and between PM hits and PM misses ($p < .05$), but not between PM misses and ongoing activity trials (p > .10). Amplitude was also greater for children than for the adults (*p*s < .01), whereas the younger and older adults did not differ significantly ($p > .10$). The comparison of ongoing activity trials to PM hits revealed a significant effect of trial, $F(1,92) = 12.95$, $p < .01$, $\eta^2 = .123$, and a non-significant age × trial interaction, $F < 1.00$, $\eta^2 = .002$ (Figure 6). Hence, the frontal positivity was observed in each age group. For the contrast comparing PM hits to PM misses we found also a significant effect of trial, $F(1,89) = 6.02$, $p < .05$, $\eta^2 = .063$, and a non-significant interaction of age × trial, $F < 1.00$, $\eta^2 = .001$. Thus, the frontal positivity discriminates between PM hits and PM misses similarly across all age groups.

Parietal positivity.

The *parietal positivity* was examined in a 3 (age) × 3 (trial: PM hits, PM misses, ongoing activity trials) × 2 (hemisphere: left (CP3-P3), right (CP4-P4)) repeated-measures ANOVA. The main effect of trial was significant, $F(2,178) = 7.57$ ($\varepsilon = .80$), $p < .01$, $\eta^2 = .072$, reflecting similar amplitudes for ongoing activity trials and PM misses ($p > .10$), but greater amplitude for PM hits ($p < .01$ for the comparison to ongoing activity trials and $p < .05$ for the comparison to PM misses). The effect of age was also significant, $F(2,89) = 47.46$, $p < .01$, $\eta^2 = .516$, with amplitude decreasing from children to younger adults ($p < .01$), and no difference between younger and older adults ($p > .10$). Furthermore, the interaction of age × trial was significant, $F(4,178) = 4.59$ ($\varepsilon = .76$), $p < .001$, $\eta^2 = .087$. Comparing ongoing activity trials to PM hits revealed a significant effect of trial, $F(1,92) = 16.88$, $p < .001$, $\eta^2 = .140$, a significant effect of hemisphere, $F(1,92) = 4.24$, $p < .05$, $\eta^2 = .042$, and a significant age × trial interaction, $F(2,92) = 5.74$, $p < .001$, $\eta^2 = .095$. Further analyses showed that the difference between ongoing activity trials and PM hits was significant for children ($p < .01$), but not for younger adults ($p < .07$) or older adults ($p > .10$). This result indicates a marked decrease in the amplitude of the parietal positivity from children to adults (Figure 6). There was a trend level interaction of age × hemisphere, $F(2,92) = 2.84$, $p < .07$, $\eta^2 = .056$. In children the amplitude was greater over the right hemisphere ($p < .01$), whereas in younger and older adults the amplitude did not differ across hemispheres (ps $> .10$). For the contrast comparing PM hits to PM misses we found a significant effect of trial, $F(1,89) = 6.79$, $p < .05$, $\eta^2 = .063$, a significant interaction of age × trial, $F(2,89) = 5.62$, $p < .001$, $\eta^2 = .105$, and a significant interaction of age × hemisphere, $F(2,89) = 4.54$, $p < .05$, $\eta^2 = .090$. These results reveal that the parietal positivity distinguishes PM hits and PM misses in children ($p < .01$), especially over the right hemisphere, but not in younger or older adults (ps $> .10$).

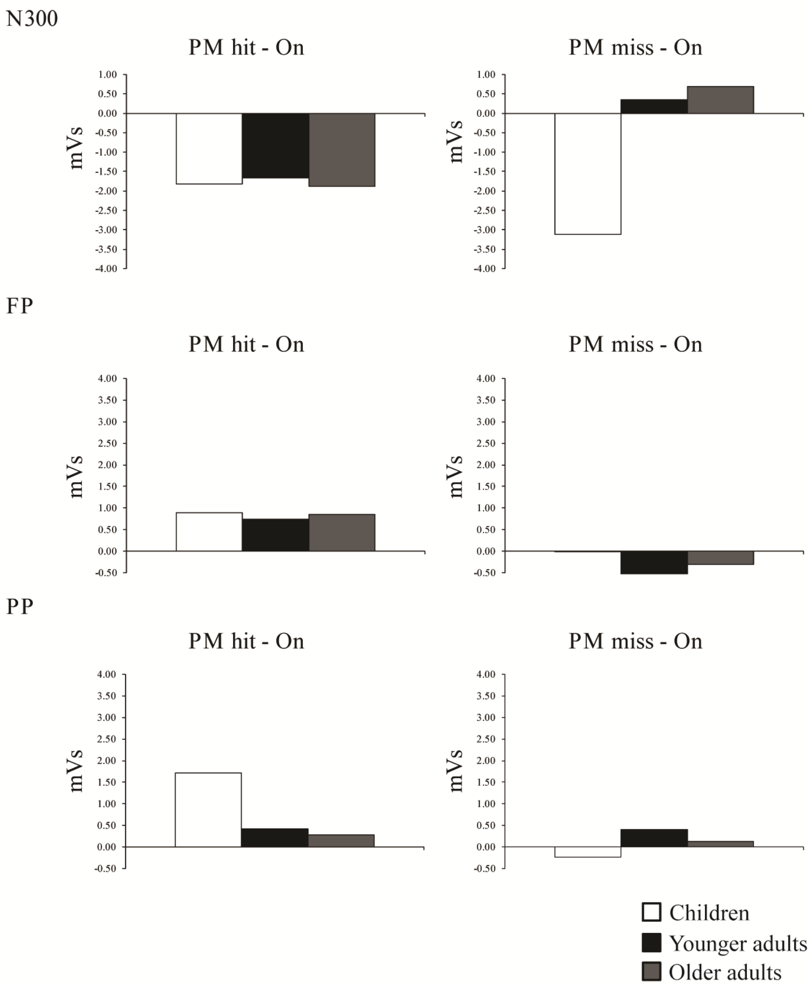

Figure 6. **Differences in mean voltage.** Depicted is the absolute difference in mean voltage (μV) between PM hit and ongoing activity (On) trials and between PM miss and ongoing activity (On) trials displaying the age × trial interaction for the N300, the frontal positivity (FP) and the parietal positivity (PP) for the three age groups.

PLS analyses

Realizing intentions.

PLS analysis was used to examine age-related differences in the spatiotemporal distribution of the ERPs associated with prospective and retrospective memory. This analysis included three age groups and ERP data for the ongoing activity trials preceding the PM cue trials, PM hits, PM misses, and RM hits from 0-1200 ms after stimulus onset at 40 electrodes. The PLS analysis revealed four significant latent variables (*p*s < .001) that accounted for 48.81%, 20.91%, 13.32%, and 7.63% of the cross-block covariance, respectively (see Figure 7).

The first latent variable contrasted RM hits and the other trials, with some variation in the expression of this latent variable across the three groups (see Figure 5 for the mean amplitudes of RM hits). In children, LV1 contrasted RM hits with ongoing activity trials and PM misses; in younger adults, LV1 contrasted RM hits with ongoing activity trials and PM hits; and in older adults, LV1 contrasted RM hits with PM hits. The electrode saliences for LV1 revealed three stable epochs of neural activity. Between 100-300 ms after stimulus onset the electrode saliences revealed phasic activity over the occipital and frontal regions of the scalp that appear to reflect differences in the amplitude of the P1 and N2 components for RM hits relative to the other trials. Between 200-800 ms after stimulus onset the electrode saliences revealed stable difference in neural activity over the parietal region that could reflect the P3b or the recognition memory old-new effect. Finally, between 300-900 ms after stimulus onset the electrode saliences revealed stable differences in neural activity over the lateral frontal region.

The second latent variable reflected a contrast between PM hits and ongoing activity trials across the three groups. In the younger adults, LV2 also contrasted PM misses with PM hits; and in the older adults, LV2 contrasted PM hits and RM hits with ongoing activity trials and PM misses. The electrode saliences revealed three stable epochs of neural activity. Between roughly 250-350 ms after stimulus onset there was a transient positivity over the posterior region that may represent the N300. Between 250-500 ms after stimulus onset there was a negativity over the midline frontal region that likely reflects the frontal positivity. Between roughly 600-1100 ms there was a sustained modulation over the parietal region of the scalp likely reflecting the parietal positivity. The pattern of brain scores and electrode saliences for this latent variable reveals that the core ERP components associated with PM are reliable across the lifespan in our sample.

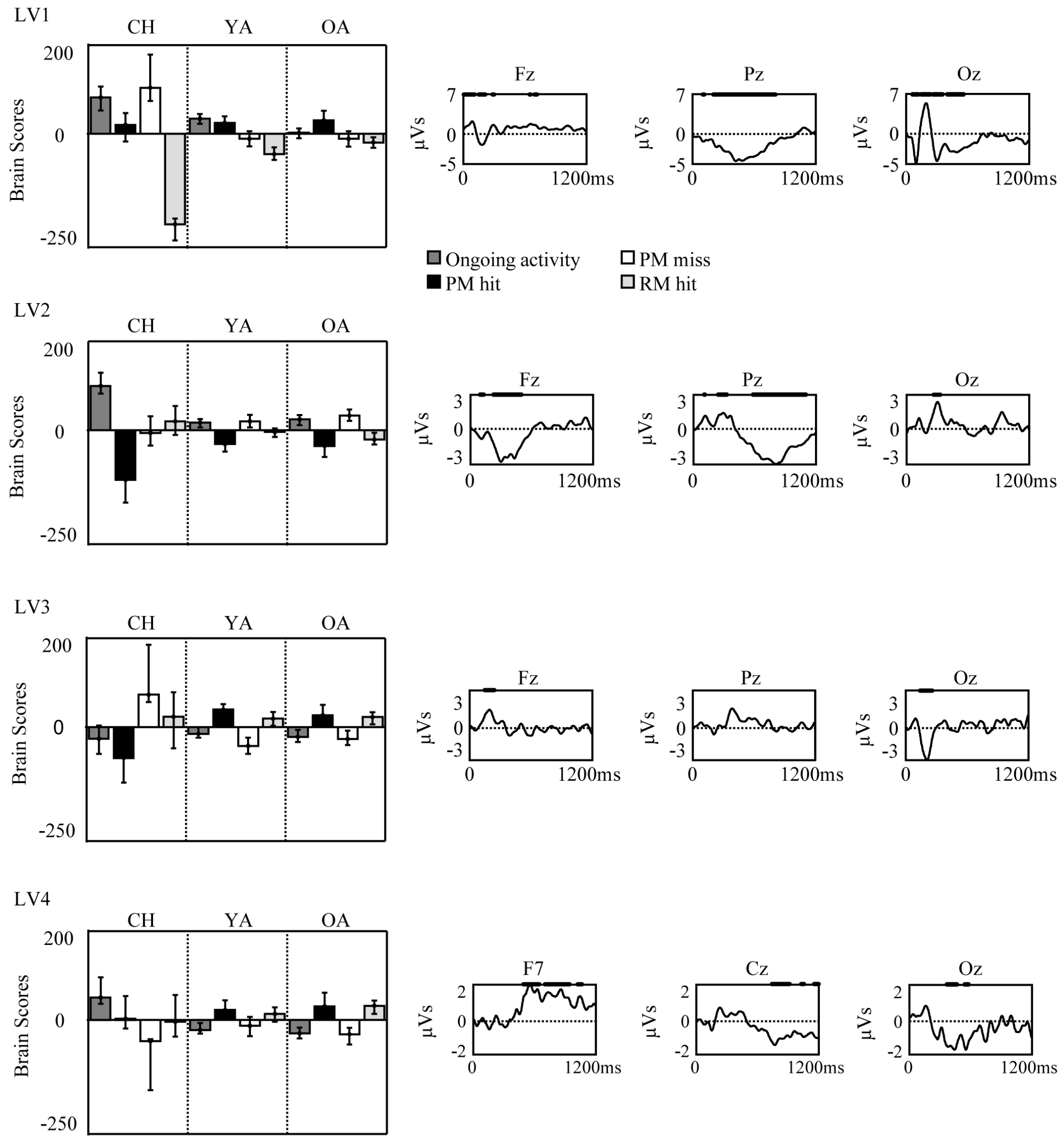

Figure 7. **PLS results for realizing intentions.** Brain scores and electrode saliences for select electrodes for the four significant latent variables from the PLS analysis examining the neural correlates of PM for children (CH), younger adults (YA) and older adults (OA). The error bars for the brain scores represent the 95% confidence intervals from the bootstrap test. The "o" above the x-axis for the electrode salience plots mark points in time where the bootstrap ration exceeded 2.5 (e.g., $p < .01$).

The third latent variable revealed a group × condition crossover interaction that contrasted PM hits with PM misses in the children, and PM hits and RM hits with PM misses and ongoing activity trials in the younger and older adults. The electrode saliences for this latent variable revealed two stable epochs of neural activity. The first represented a transient modulation over the occipital and midline frontal regions that peaked around 200 ms after stimulus onset. The second reflected a sustained modulation over the left lateral frontal region between 700-1000 ms after stimulus onset. These data may indicate that there is an age-related shift in the neural correlates of PM that emerges between childhood and adulthood, and is then relatively stable from early to late adulthood.

The fourth latent variable also revealed a quite different pattern of brain scores in the children compared to the younger or older adults. In the children, LV4 contrasted PM misses with ongoing activity trials. In younger and older adults, this LV4 contrasted PM and RM hits with ongoing activity trials and PM misses, and this effect appeared to be stronger in the older adults. The electrode saliences revealed one stable epoch of neural activity between roughly 500-600 ms after stimulus onset over the left lateral frontal and central to parietal regions. In adulthood this latent variable could be related to retrospective processes that also contribute to PM, a finding that is consistent with some previous studies examining the ERP correlates of PM (West, 2007; West & Krompinger, 2005).

Strategic monitoring.

To examine the neural correlates of strategic monitoring we conducted a PLS analysis on the data for ongoing activity trials preceding and following PM hits (West et al., 2007). The analysis included 0-1200 ms of data after stimulus onset at 40 electrodes. This analysis revealed one significant latent variable ($p < .01$) that accounted for 82.15% of the crossblock covariance (see Figure 8b). The magnitude of the difference in the brain scores decreased from children to younger adults and was similar in younger and older adults. The electrode saliences revealed sustained modulations of the ERPs extending from the left posterior to the left lateral frontal regions and over the right lateral frontal region over most of the analyzed epoch.

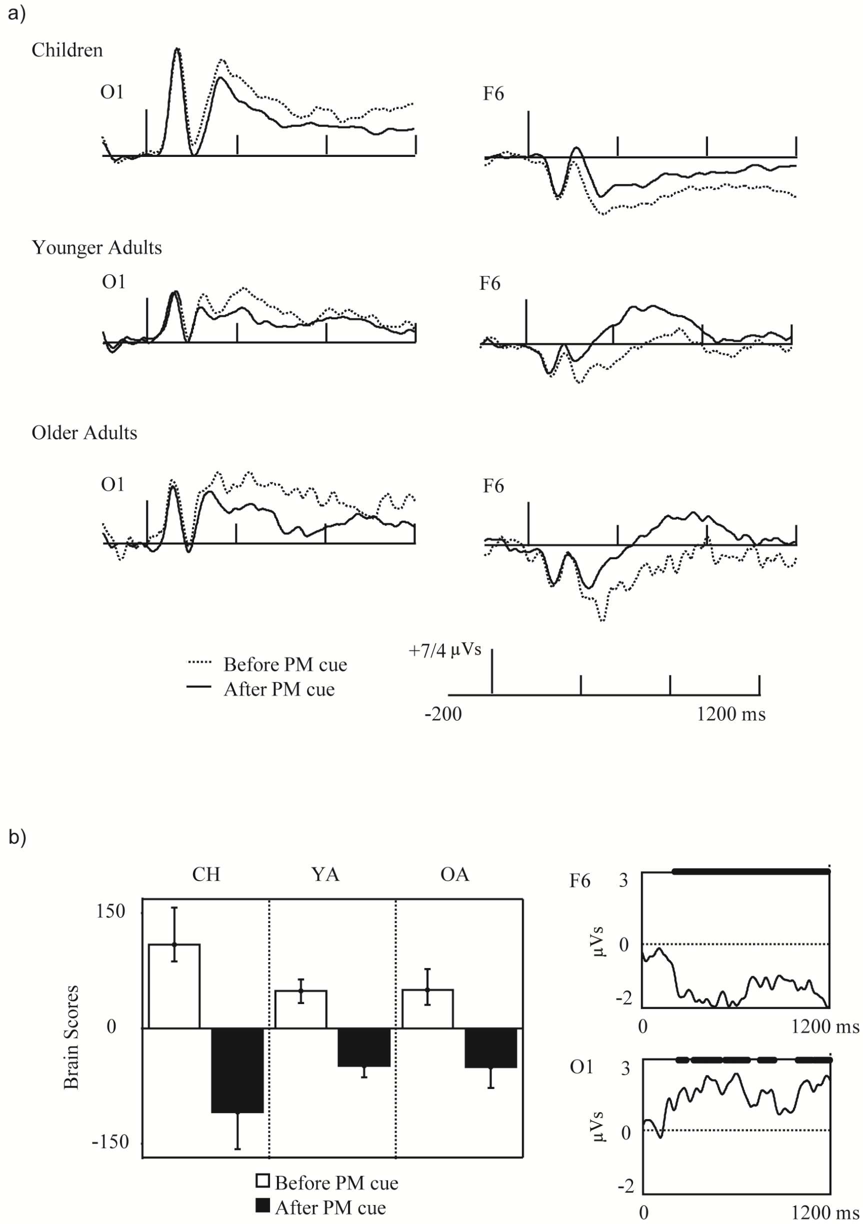

Figure 8. **Grand-averaged ERPs and PLS results associated with strategic monitoring.** (a) Grand-averaged ERPs at electrodes O1 and F6 demonstrating the slow wave activity associated with strategic monitoring (i.e., for ongoing activity trials before or after a PM hit) in the three groups of participants. The tall bar represents stimulus onset and the short bars represent 400 ms increments. The tall bar represents 7 µVs in the children and 4 µVs in the adults to account for the overall difference in amplitude between the groups. (b) Brain scores and electrode saliences for electrodes O1 and F6 for the one significant latent variable from the PLS analysis examining the neural correlates of strategic monitoring in children (CH), younger adults (YA), and older adults (OA). The error bars for the brain scores represent the 95% confidence intervals from the bootstrap test and the "o" above the x-axis for the electrode salience plots mark points in time where the bootstrap ratio exceeded 3.0 (e.g., $p < .01$).

3.2.4. Discussion

This study was designed to examine the neural correlates of age-related differences in PM across the lifespan. Response accuracy for the PM task revealed the typical inverted U-shaped distribution with accuracy increasing from childhood to young adulthood and then decreasing to later adulthood. The majority of PM errors reflected instances where an ongoing activity response was made to the PM cues rather than confusion errors where the wrong prospective response was made. These findings lead to the suggestion that variation in the efficiency of processes contributing to the prospective component primarily contributed to age-related variation in PM in the current study. To identify the neural correlates of age-related differences in PM, the ERP data were analyzed using repeated-measures ANOVA and PLS analysis. These analyses revealed several components of the ERPs that are associated with PM (i.e., N300, frontal positivity, parietal positivity, and slow wave activity related to strategic monitoring). Both analytic approaches revealed age-related variation in the pattern of neural recruitment observed during task performance and revealed that different processes may contribute to the rise and fall of PM across the lifespan.

The N300 was reliable across the lifespan in the modified PM encoding-retrieval paradigm in the mean voltage and PLS analyses. In younger and older adults the N300 distinguished PM hits from PM misses and ongoing activity trials. This finding is consistent with previous research (West, 2007; West & Ross-Munroe, 2002) and leads to the suggestion that PM errors in the younger and older adults resulted from failures to detect the PM cues. In contrast to the adults, the N300 distinguished PM hits and PM misses from ongoing activity trials in the children. This finding may indicate that children detected the PM cues on some portion of the PM error trials and that failure of PM on these trials resulted from the disruption of processes that follow cue detection and are associated with switching or disengaging from the ongoing activity. Variation in the N300 between PM hits and PM misses in children and adults leads to the suggestion that different processes may contribute to failures of PM and hence, the realization of delayed intentions in childhood and adulthood (Zöllig et al., 2007).

The frontal positivity was also robust across the lifespan, leading to the suggestion that the cognitive processes associated with this component of the ERPs were functional by middle childhood. The frontal positivity distinguished PM hits from PM misses and ongoing activity trials in the children, younger adults, and older adults. In the younger and older adults this pattern of data reveals a strong coupling of the N300 and frontal positivity, consistent with previous research (West, 2007; West et al., 2007). In contrast, in the children the N300 and frontal positivity appear to be dissociated (i.e., for the N300, PM hits equal PM misses and differ from ongoing activity trials; and for the frontal positivity, PM hits differ from PM misses and ongoing activity trials). This finding may indicate that some PM errors in the children resulted from the failure of executive processes that are associated with switching or disengaging from the ongoing activity following the detection of a PM cue (Zelazo et al., 2004).

Consistent with previous research (West, 2007; West & Krompinger, 2005), the parietal positivity differentiated PM hits from PM misses and ongoing activity trials. The reliability of this effect differed in the analysis of mean voltage and the PLS analysis. In the mean voltage analysis, the difference in amplitude between PM hits and ongoing activity trials was significant in the children but not in the younger or older adults. The reduction in the parietal positivity with increasing age is consistent with the findings of Zöllig et al. (2007) who observed a similar decrease in amplitude from adolescents to older adults. In the PLS analysis, the second latent variable captured the parietal positivity associated with PM. Furthermore, the timing and distribution of the stable electrode saliences lead to the suggestion that the parietal activity associated with the second latent variable reflects the prospective positivity. The confidence intervals for the brain scores for PM hits did not include zero for any of the groups indicating that the effect was reliable in all three age groups. Although the brain scores for PM hits are clearly larger for children than for younger or older adults. The results of the PLS analysis for the second latent variable are similar to those reported by Zöllig et al. for their first latent variable. Together these data lead to the conclusion that neuro-cognitive processes associated with the prospective positivity (e.g., task set configuration, West, 2011) contribute to successful PM across the lifespan.

Based upon some previous research (West & Krompinger, 2005; West et al., 2007), one could expect to observe some overlap in the ERPs elicited by PM hits and RM hits reflecting the contribution of explicit episodic memory processes to performance in these two types of trials (Einstein & McDaniel, 1996). The pattern of brain scores for the third and fourth latent variables in the younger and older adults is consistent with the general idea (i.e., in the younger and older adults these two latent variables tended to contrast PM and RM hits with PM misses and ongoing activity trials). However, when the distribution of the stable electrodes saliences for the two latent variables is also considered it seems that only the fourth latent variable is likely related to the retrospective component of PM. Specifically, this latent variable revealed stable electrode saliences over the central-parietal and lateral frontal regions of the scalp between 500-1200 ms after stimulus onset. If one assumes that the memory retrieval demands of the PM encoding-retrieval task are more similar to cued-recall than recognition, then the pattern of electrode saliences would be consistent with the findings of West and Krompinger (2005, Experiment 2) related to PM, as well as, more generally to ERP studies of the neural correlates of cued-recall (Allan & Rugg, 1998). The pattern of brain scores for the children for this latent variable was quite different from that observed for younger and older adults. This finding may be consistent with the idea that retrospective processes underpinning PM are not fully developed until early adulthood (R. E. Smith et al., 2010).

Like the fourth latent variable, the pattern of brain scores for the third latent variable was quite different in children and younger and older adults. This latent variable primarily expressed early transient neural activity over the posterior and midline frontal regions that may reflect modulations of the posterior N2 and anterior P2 components of the ERPs.

The association of this latent variable with successful PM in the children, differences between the children and the older two age groups, and the lack of stable electrode saliences over the parietal region for the third latent variable may indicate that this effect is associated with processes that support cue detection, rather than memory retrieval, in children and that this becomes less critical for the success of PM in early and later adulthood.

The reason for such a developmental shift in the processes supporting PM is unclear based upon the available evidence, and could be related to developmental differences in the ability to bring to bear executive control process early and later in life to support PM.

RM hits, relative to ongoing activity trials, were associated with modulations of the amplitude of the P1 and N2 over the occipital region of the scalp and the P3b over the parietal region of the scalp. These effects were much greater in children than in adults. In the PLS analysis, these differences were captured by the first latent variable that contrasted the ERPs elicited by RM hits with those elicited by ongoing activity trials, PM hits, or PM misses depending upon which group is considered. The contribution of the early visual components and the relatively symmetrical distribution of the effect over the left and right parietal regions may indicate that this pattern of neural activity is more strongly related to the relative distinctiveness of the RM cue displays, representing a target or oddball effect, rather than reflecting the neural correlates of recognition memory.

The analysis designed to examine the neural correlates of strategic monitoring revealed sustained neural activity over frontal and posterior regions of the scalp that differentiated ongoing activity trials preceding or following PM hit trials. This finding is consistent with evidence from previous research using ongoing activities that required semantic judgments (West et al., 2007) or monitoring items held in working memory (West et al., 2006). Together, the results of the current and previous research may indicate that the frontal and posterior sustained activity related to strategic monitoring represents a relatively general response as it is observed with different ongoing activities. The sustained activity related to strategic monitoring was robust across the lifespan, and the size of the brain scores was relatively consistent in the younger and older adults. This finding may indicate that within the current sample cognitive processes related to strategic monitoring in PM were relatively independent of age. This conclusion seems inconsistent with the idea that age-related increases and then declines in the efficiency of monitoring processes contribute to the development of PM across the lifespan. However, it is possible that age is associated with variation in the likelihood of engaging in strategic monitoring over time rather than the strength of the effect of monitoring. A comparison of ongoing activity trials preceding PM encoding trials with those preceding PM hits or misses could provide insight into this explanation. Furthermore, the inclusion of source localization methods of ERPs and other brain imaging methods such as PET and functional MRI could further contribute, when linked to previous findings in prospective memory research (e.g., Burgess, Quayle, & Frith, 2001; Simons, Schölvinck, Gilbert, Frith, & Burgess, 2006; Zöllig & Eschen, 2009), to the understanding of differential mechanisms engaged in prospective memory functioning across the lifespan.

There was a relatively dramatic difference in the accuracy of prospective memory between younger and older adults; in contrast, at the neural level age-related differences between these two groups were more modest. One possible explanation for this seemingly counterintuitive effect is that younger and older adults may differ in the likelihood of engaging in controlled attentional or preparatory processes that facilitate PM (Smith & Bayen, 2004) rather than in their ability to utilize these processes to support PM. Consistent with this idea, evidence from studies examining age-related differences in selective attention (West, 1999) and working memory (West, Murphy, Armilio, Craik, & Stuss, 2002) indicate that older adults are more susceptible to lapses of attention than are younger adults, and that these lapses of attention may contribute to age-related differences in PM (West & Craik, 1999).

In conclusion, the current study used ERPs to examine the basis of age-related differences in the neural correlates of PM retrieval across the lifespan. Our data revealed that PM errors in younger and older adults appeared to result from instances where individuals failed to detect the PM cues. In contrast, PM errors in children may have resulted from a breakdown in the coupling of processes associated with cue detection and signaling a switch or disengagement from the ongoing activity. These findings provide support for the idea that different processes contribute to age-related variation in the success of PM early and late in life.

3.3. Electrophysiological activity during the intention formation phase: An addendum to study II[4]

As mentioned in the general introduction of this thesis, prospective memory constitutes a process including at least four phases (and even more subphases). Success in a prospective memory task presumes the successful fulfillment of all of the phases and subphases (Ellis, 1996). Accordingly, failed prospective memory execution can occur due to failures in any of the phases (Ellis & Freeman, 2008). In the second research question of this thesis, the point in the process at which a failure occurs was scrutinized. With results of study 2, it was possible to answer this question within the retrieval interval, that is in phases 3 (the intention-initiation) and 4 (the intention-execution) of the prospective memory process. Obviously, it cannot be ruled out that at least in some instances the reason for the failure is grounded in phase 1 (the intention- formation) or phase 2 (the intention-retention). With respect to the intention-formation phase, I have conducted some supplementary analyses that I would like to present here as an addendum.

Former studies that have looked at the electrophysiological activity during the intention-formation phase described specific components of the event-related potentials (West, Herndon et al., 2003; West, Jakubek, & Wymbs, 2002; West & Ross-Munroe, 2002; Zöllig et al., 2010). These components are: the late positive complex (LPC), the fronto-polar slow wave (FPSW), and the temporo-parietal slow wave (TPSW). Only two of these, the FPSW and the TPSW differentiate between subsequent successful prospective memory trials and failed prospective memory trials (West, Herndon et al., 2003; West & Ross-Munroe, 2002). The underlying concept for this path of research is the *difference due to subsequent memory effect* or short *DM-effec*t (Paller & Wagner, 2002). This effect describes higher amplitudes of the event-related potentials during presentation of to-be-remembered items for subsequently successfully remembered items as compared to later not-remembered items. The FPSW during intention-formation trials within a prospective memory paradigm reflects a sustained negativity, between about 500-1000 ms after stimulus onset over the frontal-polar brain region. The TPSW represents a sustained positivity over the temporo-parietal region, between 800-1200 ms after stimulus onset.

[4] This addendum is not part of the published manuscript

Important to note are age-related differences in these components (West, Herndon et al., 2003). The FPSW differentiated only between subsequent prospective memory hits and misses in young adults, but not in old adults. In contrast, the TPSW was only predictive for later successes or failures in older adults.

Based on these findings, I inspected the electrophysiological data during intention-formation trials in the three age groups from study 2 in terms of the amplitude differences between subsequent prospective memory hits and misses. For the FPSW, I performed a 2 (trial: subsequent prospective memory hit, subsequent prospective memory miss) × 2 (electrode: FP1, FP2) × 3 (group: children, young adults, old adults) repeated-measures ANOVA. Results revealed that neither the main effect of trial, nor any of the interactions with trial was significant (main effect of trial: $F < 1.00$, $\eta^2 < .001$, trial × group: $F < 1.13$, $\eta^2 = .025$, trial × electrode: $F < 1.00$, $\eta^2 = .011$, trial × electrode × group: $F < 1.00$, $\eta^2 = .006$).

Accordingly, for the TPSW I performed a 2 (trial: subsequent prospective memory hit, subsequent prospective memory miss) × 2 (electrode: TP7, TP8) × 3 (group: children, young adults, old adults) repeated-measures ANOVA. This analysis also revealed neither a significant main effect of trial, nor any significant interaction with trial (main effect of trial: $F < 1.00$, $\eta^2 = .002$, trial × group: $F < 1.21$, $\eta^2 = .027$, trial × electrode: $F < 1.00$, $\eta^2 = .002$, trial × electrode × group: $F < 1.00$, $\eta^2 = .014$).

3.4. Study III: Automatization of event-related prospective memory retrieval: Diverging findings in young and old adults[5]

3.4.1. Introduction

Event-based prospective memory (PM) tasks reflect instances where a person creates an intention, retains the intention over a variable amount of time while dealing with other tasks, and recalls and realizes the intention upon the occurrence of a specific event. The designs used to assess PM vary greatly between studies depending on the main research focus. For example, some researchers tried to simulate everyday life situations in their PM tasks (e.g., P. E. Bailey et al., 2010; Maylor, 1990; Rendell & Thomson, 1993, 1999), whereas other groups of researchers designed elaborate laboratory paradigms to isolate the different processes of PM (e.g., Einstein & McDaniel, 1990; Kliegel & Jäger, 2006; Phillips et al., 2008).

One aspect that varies between the different paradigms is the absolute number of PM events applied to measure PM performance. Pure behavioral studies were conducted with only a single PM event (e.g., the red pen task, Dobbs & Rule, 1987) but also with up to four (e.g., Zimmermann & Meier, 2006), 16 (e.g., Einstein et al., 2000; R. E. Smith et al., 2011), or 20 PM events (West & Craik, 1999). On the other extreme are studies using event-related potentials (ERPs) of the electro-encephalogram (EEG) to investigate the temporal characteristics of the neural signal associated with PM (e.g., Bisiacchi et al., 2009; Knight, Ethridge, Marsh, & Clementz, 2010; Mattli et al., 2011; West, 2011; West, Herndon, & Ross-Munroe, 2000; West & Krompinger, 2005; West & Ross-Munroe, 2002; Zöllig et al., 2007). Due to methodological requirements, these studies repeat PM events up to 70 times (Knight et al., 2010) to increase the signal-to-noise-ratio (Luck, 2005).

This variation in the absolute number of PM events (i.e., 1 or 70) may, however, lead to considerable variation in the processes recruited to perform the PM task (Ellis et al., 1999). An early model proposed by Schneider and Shiffrin (1977) could already indicate that attentional demands of a cognitive processes (i.e., visual

[5] A similar version of this chapter has been submitted for publication at the “Quarterly Journal of Experimental Psychology” (Mattli & Zöllig).

and memory search and target detection in their studies) decrease as a result of repetition and increasing automatization. They claimed that a considerable amount of consistent repetition leads to the development of automatic responses that operate through a permanent set of associative connections. These automatized responses will then automatically direct controlled processing to the target. In contrast, in a study conducted by Ellis and colleagues (Experiment 2, 1999), results revealed that PM performance was significantly higher in the first section as compared to the four subsequent sections of their paradigm.

To disentangle these conflicting findings, the question of the present study is whether behavioral and electrophysiological measures change in the course of multiple repetitions of a PM event. According to the automatic associative model of PM (Guynn, McDaniel, & Einstein, 2001; McDaniel, Robinson-Riegler, & Einstein, 1998), an intention is realized successfully if a PM cue interacts with the associated memory trace. If the association of cue and memory trace is strong enough, the authors suggest that the interaction can occur automatically. Cohen and Gollwitzer (2008) have shown that increased accessibility of an intention, for example through detailed planning, can lead to a strong association and as a consequence induce more automaticity. Similarly, we would assume that repetition of PM events strengthens the association between cue and intention and increases accessibility of the intention.

ERP-correlates of prospective memory

With regard to the electrophysiology of PM, three specific modulations of the event-related brain potential (ERP) have been described: the *N300*, the *frontal positivity*, and the *parietal positivity* (e.g., West, 2011; West et al., 2001; West & Ross-Munroe, 2002). The *N300* represents a stronger negativity for PM hits compared to ongoing activity trials that starts approximately 200-400 ms after stimulus presentation and is maximally pronounced over occipito-parietal scalp regions. Former studies give evidence for the N300 reflecting the electrophysiological activity of processes associated with detection of an event-based PM cue in the environment that initiates the intention (e.g., Mattli et al., 2011; West et al., 2001; West et al., 2002). It has been described to depend upon the efficiency and allocation of controlled attentional resources. The less efficient the controlled attentional resources are, the more they have to be activated to successfully complete a PM task and this is associated with a reduction in the N300 amplitude(e.g., in old age, West, 2011; West & Covell, 2001; West, Herndon et al., 2003). Three further findings corroborate this assumption: first, West and colleagues (2005; 2006) showed that attentional resources needed to complete a task increase with task complexity (i.e., PM cue embedded in a 3-or 2-back versus a 1-back task) and this was associated with a lower amplitude of the N300. Second, West, Wymbs, Jakubek & Herndon (2003) found the N300 to be reduced if the PM cue was not distinct (mixed background color compared to uniform background color). Reduced distinctiveness of the PM cue demands more attentional resources for detection. And third, in our own lab, we found that the N300 was increased as a result of familiarization with the PM task which led to more efficient attentional resource recruitment in an intervention group (Zöllig et al., 2012). This inverse relation of attentional effort and N300 amplitude may reflect a suppression effect insofar as the amount of activated attentional resources operate in a suppressing way on the amplitude of the N300. Findings of West et al. (2006) substantiate this conclusion showing that PM performance was not affected by the varied N-back load of the ongoing activity but the N300 was decreased in the increased N-back load; hence the authors concluded that higher attentional effort was allocated to complete the PM task under the more demanding condition.

The N300 is accompanied by the *frontal positivity*, which is a stronger positivity for PM hits compared to ongoing activity trials, over medial frontal regions that lasts beyond the duration of the N300 (West et al., 2001; West & Krompinger, 2005). The neurocognitive processes associated with the frontal positivity are less clear. Recently, it has been described as a modulation that is associated with an executive control process that supports switching the attention between the ongoing activity and PM task (Bisiacchi et al., 2009; West, 2011). Based on aging research, it has been suggested (West, Herndon et al., 2003) that a decreased amplitude of the frontal positivity is related to a reduction in the efficiency of switching mechanisms and as a result slowed responding in PM trials. Accordingly, the authors found that variation of cognitive load (i.e., N-back load) and as a consequence the demands put upon executive control processes did have a significant effect on the reaction times in PM cue trials, with slower reaction times in the 2-back than in the 1-back condition, indicating compromised switching abilities under the more demanding condition.

However, for young adults, this effect seems not to be robust, as in another study by West and colleagues (2006), reaction times did not differ as a consequence of cognitive load. Accordingly, previous research about attention shifting revealed that reaction times of old adults are more affected than young adults', slowing under conditions where attention must be switched between two concurrent tasks (Verhaeghen & Cerella, 2002). Nevertheless, in young adults, the amplitude of the frontal positivity seemed to be reduced in the more challenging condition, although the authors did not give any information about significance of this effect (see Fig. 1 in West et al., 2006). Additionally, partial least square analyses (PLS, e.g., Lobaugh, West, & McIntosh, 2001) showed that cognitive load did have an influence on the electrophysiological signal over frontal brain regions (West et al., 2006).

The parietal positivity reflects a stronger positivity for PM trials compared to ongoing activity trials that is predominantly found over central and parietal brain regions. It starts around 600 ms after stimulus presentation (West, 2011; West et al., 2006; West, Herndon et al., 2003; West et al., 2001; West & Ross-Munroe, 2002; Zöllig et al., 2007) and it reflects the integration of three distinct modulations of the ERP: the P3b, the recognition old-new effect, and the prospective positivity (West, 2005, 2011; West & Ross-Munroe, 2002). The proportional contribution of the P3b depends upon the cue salience: non-salient cues reduce the influence of the P3b upon the parietal positivity. The recognition old-new effect is associated with processes that support intention retrieval from memory. The prospective positivity constitutes an executive control process that supports the configuration of a prospective task set (Bisiacchi et al., 2009; West, 2011). The amplitude of the parietal positivity has not been found in either young nor old adults to be influenced by varying cognitive load, that is difficulty of the task (West & Bowry, 2005; West et al., 2006). Furthermore, in studies with non-salient PM cues, the amplitude of the parietal positivity did not differ between young and old adults. Thus, the more PM specific modulations of the parietal positivity – that is the intention retrieval and the prospective task set – seem to be insensitive to different levels of efficiency of executive control processes (West, Herndon et al., 2003).

The studies described above (e.g., Bisiacchi et al., 2009; Knight et al., 2010; Mattli et al., 2011; West et al., 2006; Zöllig et al., 2007) used different numbers of PM events for calculating the average amplitude within each person, i.e., the ERP. By this account, potential changes across earlier (with less repetition) and later (with more routine) occasions of successful PM execution remain concealed. The purpose of the current study was to examine changes in reaction times and ERP modulations of PM across blocks of early, middle, and late PM hits as a result of a transition to more automatic and efficient PM in young and old adults. Changes in reaction times and the modulations of the ERPs may reflect the transition from attentionally demanding intentional behavior to instances of goal-directed automaticity (Verplanken & Aarts, 1999).

Our predictions for changes in reaction times were that young and old adults' reaction times for PM hits may decrease across multiple repetitions of the PM event as a result of higher accessibility and stronger associations between the PM cue and intention. It may reflect a correlate of the transition to more automatic and hence less effortful PM (Glisky, 2007; Schneider & Shiffrin, 1977) and particularly for old adults, show an additional sign of more efficient switching abilities (West, Herndon et al., 2003). Furthermore, as a consequence of more efficient attentional resources, task costs may decrease with the repetition of PM events, with ongoing reaction times are getting faster (Experiment 2, McDaniel et al., 2008).

For the N300 we expect its amplitude to be greater in later trials than in earlier trials for both young and old adults. This assumption is based on the aforementioned inverse relation between attentional resources and the N300 amplitude. We would propose that the more a PM event is repeated the less attentional resources have to be activated because of more automatic cue-detection and this is associated with a more pronounced N300. For the frontal positivity, we propose the amplitude should increase as a correlate of a higher efficiency in switching between the two concurrent tasks. Concerning the parietal positivity, we do not expect its manifestation to be significantly influenced by potential automatization effects, because former evidence demonstrated that in paradigms with low-salient PM cues, the amplitude of the parietal positivity is unaffected by the designation or efficiency of attentional processes in neither young nor old adults.

3.4.2. Methods

Participants

A total of 48 subjects divided into two groups were included in the study: 24 young adults (*M* = 22.29 years, *SD* = 2.46, 15 female), and 24 old adults (*M* = 70.67 years, *SD* = 4.69, 11 female). The old adults were part of a larger sample (*N* = 78) and were selected based on the performance criterion that subjects should reach 30 or more PM hits. Overall, 57 old adults reached this criterion and among these we randomly selected 24. Accordingly, it should be kept in mind that the sample of old adults may represent a high-functioning senior group and not necessarily a representative sample of this age class.

All participants were in good health and none reported brain injuries, psycho-affective medication, drug consumption or diseases affecting brain functioning. All participants were native German speakers. A standard psychometric battery including psychomotor speed, mental flexibility, verbal memory, digit and spatial memory span, verbal fluency, and crystallized intelligence was used to screen for participants scoring more than one standard deviation below age appropriate norms. However, no one had to be excluded due to poor performance on the psychometric battery. In the EEG-analyses, the data for two participants were excluded due to technical problems (one young and one old adult).

Young adults were undergraduate students of the University of Zurich. Old adults were recruited through a newspaper article. The experiment was conducted in agreement with the declaration of Helsinki and was approved by the institutional ethics committee. Informed consent was obtained from all participants. Participants were either paid 30 CHF or received course credit.

Materials and procedure

The PM task used in this study was a simplified version of the paradigm used in Mattli, Zöllig, and West (2011). The task included 50 PM events that were embedded in a total of 505 ongoing activity trials with seven or twelve ongoing trials between each PM event. The experiment was divided into two blocks and required approximately 20 minutes to complete.

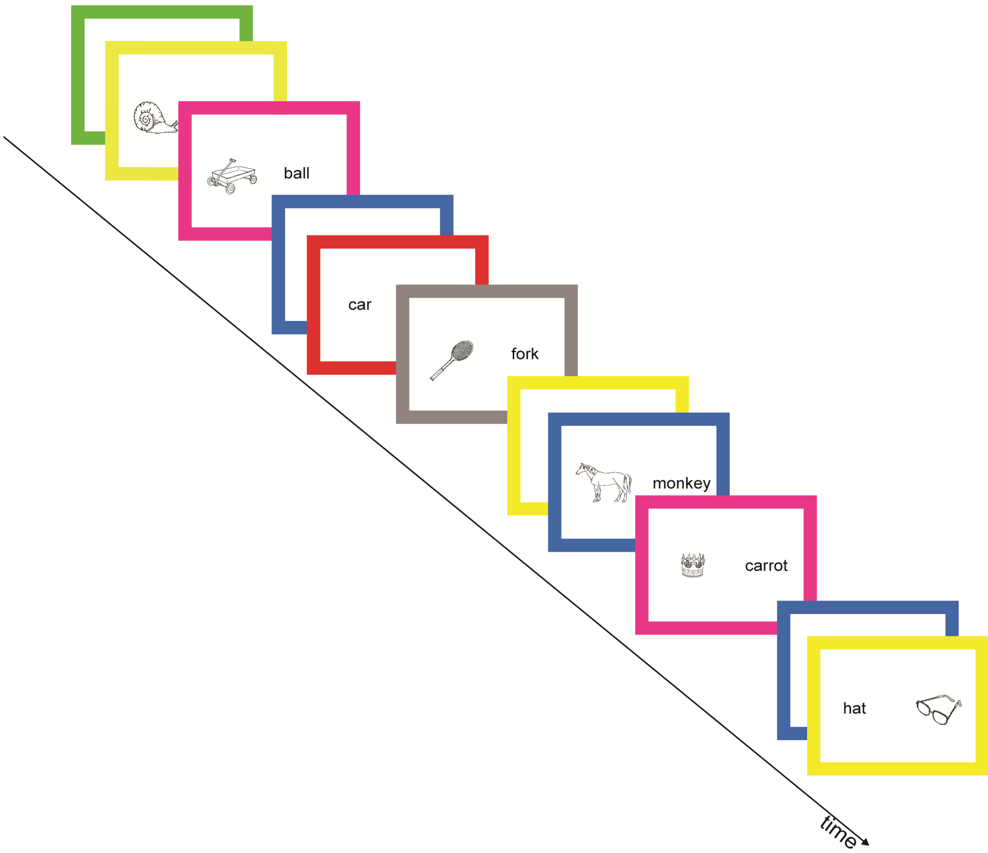

Figure 9. **The paradigm of study 3.** Illustration of the prospective memory paradigm used in the present study. Displayed is one of totally 50 analogue sequences consisting of a PM cue trial embedded in an ongoing activity.

Ongoing activity.

The ongoing activity was a semantic categorization task. For each trial one picture and one word, in lowercase letters and black color, were presented on a white background computer screen centered on the horizontal axis. Participants had to decide whether or not the picture and word belonged to the same semantic category by pressing “n” with the right index finger for “yes” and “m” with the right middle finger for “no”. The picture-word pairs were surrounded by a colored frame in one of six different colors (i.e., blue, green, red, yellow, grey, or magenta) that was irrelevant to the ongoing activity.

PM task.

Embedded in ongoing activity was the PM task. Every time the frame around the picture-word pair was magenta, participants were expected to press “c” instead of “yes” or “no”. A *PM hit* represented pressing “c” for the trial where the frame was magenta.

Participants were trained in two short blocks that could be repeated until the task was fully understood. The first block followed the instruction for the ongoing activity and consisted of 20 semantic categorization trials. The second block started after the instruction for the PM task and consisted of 23 ongoing activity trials and three PM tasks. Participants were encouraged to ask questions during and after the practice blocks to ensure that they understood the instructions before the experimental blocks began.

Stimuli.

The stimuli for the semantic categorization task were taken from a standardized set of 260 pictures of objects (simple black line drawings, Snodgrass & Vanderwart, 1980). Eighty-two pictures that belonged to ambiguous or unfavorable categories such as weapons or smoking utensils were excluded. The objects represented in the remaining 178 pictures were presented four times in the task, twice as a picture and twice as the associated word. Each object appeared twice in a related picture-word pair and twice in an unrelated picture-word pair.

The duration of stimulus presentation for the ongoing activity and PM cue trials was set to a minimum of 1600 ms and a maximum of 2800 ms. When participants responded after 1600 ms the next trial occurred after an inter-stimulus interval (ISI) of 250 ms. A response latency shorter than 1600 ms was filled with a blank screen until 1600 ms was reached, followed by the ISI. If participants did not answer after 2800 ms the ISI appeared and the next trial was presented.

The response keyboard was prepared with a cover that left only the three keys visible that were used for the task. The keys were renamed and labeled accordingly to ensure clarity for participants.

Recording and processing of electrophysiological data

Recording.

The EEG was recorded at 500 Hz with a DC QuickAmp amplifier (DC-500 Hz; Brain Products GmbH) and a 22 bit A/D converter (Vision Recorder, Brain Products GmbH) from 60 unipolar active scalp electrodes[6] placed with an EasyCap (FMS Falk Minow Services, Easycap GmbH) and two bipolar Ag/AgCl-electrodes to record vertical and horizontal eye movements. During recording an inter-electrode impedance of below 10kΩ, and no filter was applied. An average reference was used.

Processing.

The Vision Analyzer 2 software (Brain Products GmbH) was used for offline processing of the EEG data. The data were bandpass-filtered (0.1 Hz – 30 Hz, time constant 1.591549, 48 dB/oct) and an additional 50 Hz notch filter was applied. Independent component analysis (ICA) was used to correct muscular and ocular artifacts. Artifacts were eliminated by manual inspection of the data comparing the ocular components, the timing and topographical distribution of the artifacts against that of the independent components. Finally, the semiautomatic Raw Data Inspector (Vision Analyzer 2 software, Brain Products GmbH) was applied to reject residual artifacts.

In a first step, ERPs were averaged for PM hits and ongoing activity trials immediately preceding PM cues to check for the general occurrence of the PM specific modulations. In a second step, ERPs were averaged for the first 30 PM hits and ongoing activity trials in groups of ten resulting in three blocks. The stimulus-locked ERP epoch included a 200 ms prestimulus baseline and 1200 ms of poststimulus activity.

[6] The electrodes we used were the following: FP1, FPz, FP2, AF7, AF3, AF4, AF8, F7, F5, F3, F1, Fz, F2, F4, F6, F8, FT7, FC5, FC3, FC1, FCz, FC2, FC4, FC6, FT8, T7, C5, C3, C1, Cz, C2, C4, C6, T8, TP7, CP5, CP3, CP1, CPz, CP2, CP4, CP6, TP8, P7, P5, P3, P1, Pz, P2, P4, P6, P8, PO7, PO3, POz, PO4, PO8, O1, Oz, O2

Statistical analyses

Reaction time analyses.

We averaged reaction times for an early, a middle, and a late block of trials (block 1: mean of trials 1-10, block 2: mean of trials 11-20, block 3: mean of trials 21-30). The resulting three blocks were then analyzed by repeated-measures ANOVAs and planned non-orthogonal (repeated) contrasts were performed separately for the two groups.

Mean amplitude.

First, the general occurrence of the modulations was tested using a repeated-measures ANOVA comparing mean amplitude. The selection of epoch and electrodes for the analyses was guided by findings of previous research (e.g., West et al., 2001; West & Krompinger, 2005; Zöllig et al., 2007) and visual inspection of amplitude and topography of the grand-averages. The amplitude of the N300 was measured as mean amplitude between 256-306 ms after stimulus onset for young adults and between 290-340 ms for old adults, and included data for six electrodes (P1, Pz, P2, PO3, POz, PO4, O1, Oz, O2) for both groups. The amplitude of the frontal positivity was measured as mean activity between 282-332 ms for young adults and between 322-372 ms for old adults and included electrodes FP2, AF4, AF8, F4, F6, F8, FC6, FT8. Finally, the amplitude of the parietal positivity was measured as mean amplitude between 630-730 ms for young adults and between 728-828 ms for old adults, and the analyses included data of electrodes C1, Cz, C2, C3, C4, CP1, CPz, CP2, CP3, CP4. The analyses included data for PM hits and ongoing activity trials preceding PM cues. The Greenhouse-Geisser corrected degrees of freedom were applied if sphericity could not be assumed.

To check for possible automatization effects in the electrophysiology, we divided the experiment into an early, a middle, and a late block (block 1: PM hits and preceding ongoing activity trials 1-10, block 2: respective trials 11-20, and block 3: respective trials 21-30) and compiled mean amplitudes for each block in the same time frames and at the same electrodes as in the overall analyses. We then analyzed the amplitude size in the three blocks for each of the neural modulations in repeated-measures ANOVAs. As we are particularly interested in within-group changes over time all the analyses are first conducted for young adults and are in a second step separately done for old subjects.

3.4.3. Results

PM accuracy

Because we selected the group of old adults based on a performance criterion we did not analyze group differences in PM accuracy. However, mean accuracy for young adults was 45.46 (SD = 4.98) and for old adults it was 42.17 (SD = 4.29).

Changes in reaction times

Mean reaction times in young and old adults for PM hits and ongoing activity trials for blocks 1 to 3 are displayed in Table 4. Changes in reaction times in young adults across multiple blocks were analyzed in a 2 (condition: PM hits, ongoing activity trials) × 3 (block: 1, 2, 3) repeated-measures ANOVA. This analysis revealed significant effects of condition, $F(1,23) = 127.08$, $p < .01$, $\eta^2 = .847$ (PM hits < ongoing activity trials), and of block, $F(2,46) = 13.21$, $p < .01$, $\eta^2 = .365$. Importantly, the interaction of block × condition was significant, $F(2,46) = 3.90$, $p < .05$, $\eta^2 = .145$. To disentangle this interaction we performed separate analyses for PM hits and ongoing activity trials. The repeated-measures ANOVA for young adults for PM hits revealed a significant effect of block, $F(2,46) = 6.79$, $p < .01$, $\eta^2 = .228$. Non-orthogonal (repeated) planned contrasts showed that reaction time did not change from block 1 to block 2 ($p > .10$), but decreased significantly from block 2 to block 3 ($p < .05$). The analysis for ongoing activity trials revealed for young adults a significant effect of block, $F(2,46) = 10.43$, $p < .05$, $\eta^2 = .312$, indicating a stable reaction time in block 1 and 2 ($p > .10$), but a significantly smaller reaction time in block 3 compared to block 2 ($p < .01$).

The decrease in reaction time from block 2 to block 3 seems to be more pronounced (since the overall interaction of block × condition was significant) in ongoing activity trials compared to PM hits (see Table 4).

These changes in reaction time in both the PM task and the ongoing activity across blocks may represent decreasing task costs and a training effect due to more efficient attentional resources and higher accessibility or a stronger association between the PM cue and the memory trace for the intention.

For old adults the reaction time analysis revealed that the effect of block did not reach significance, $F < 1.34$, $\eta^2 = .055$, whereas the effect of condition was significant, $F(1,23) = 144.41$, $p < .01$, $\eta^2 = .863$ (PM hits < ongoing activity trials). The interaction of block × condition did not reach significance, $F < 1.21$, $\eta^2 = .050$, indicating no differential changes across blocks in conditions.

Table 4. **Mean reaction times (in ms) for young and old adults in PM hits and ongoing activity trials for blocks 1 to 3.**

	Condition						Statistics		
	PM hits			Ongoing activity			Effect of condition	Effect of block	Interaction
	Block 1	Block 2	Block 3	Block 1	Block 2	Block 3			
Young adults									
M	829.51	809.48	759.19	1329.53	1277.50	1155.43	127.08** ($\eta^2 = .847$)	13.21** ($\eta^2 = .365$)	3.90* ($\eta^2 = .145$)
SD	107.44	120.29	108.92	278.48	257.21	238.10			
Old adults									
M	946.34	922.80	908.05	1509.39	1437.37	1492.35	144.41** ($\eta^2 = .863$)	1.33 ($\eta^2 = .055$)	1.20 ($\eta^2 = .050$)
SD	168.37	216.91	197.37	237.54	250.31	258.42			

Inferential statistics for the main effects of condition and block and the interaction of block × condition are presented as *F*-ratio. * $p < .05$, ** $p < .01$.

Electrophysiological results

The ERPs at selected electrodes and the topographical maps depicting the N300, frontal positivity and parietal positivity for blocks 1, 2, and 3 and the grand-average are presented in Figure 10 and in Figure 11.

N300 in young adults.

Overall. For young adults, the 2 (condition: PM hits, ongoing activity trials) × 9 (electrodes: P1, Pz, P2, PO3, POz, PO4, O1, Oz, O2) repeated-measures ANOVA checking for the general occurrence of the N300 revealed significant effects of condition, $F(1,22) = 34.30$, $p < .01$, $\eta^2 = .609$ (PM hits > ongoing activity trials) and of electrode, $F(8,176) = 15.98$, $p < .01$, $\eta^2 = .421$. Furthermore, the interaction of condition × electrode was significant, $F(8,176) = 5.27$, $p < .01$, $\eta^2 = .193$. However, the N300 (i.e., effect of condition) was significant at each electrode (all *p*s < .01).

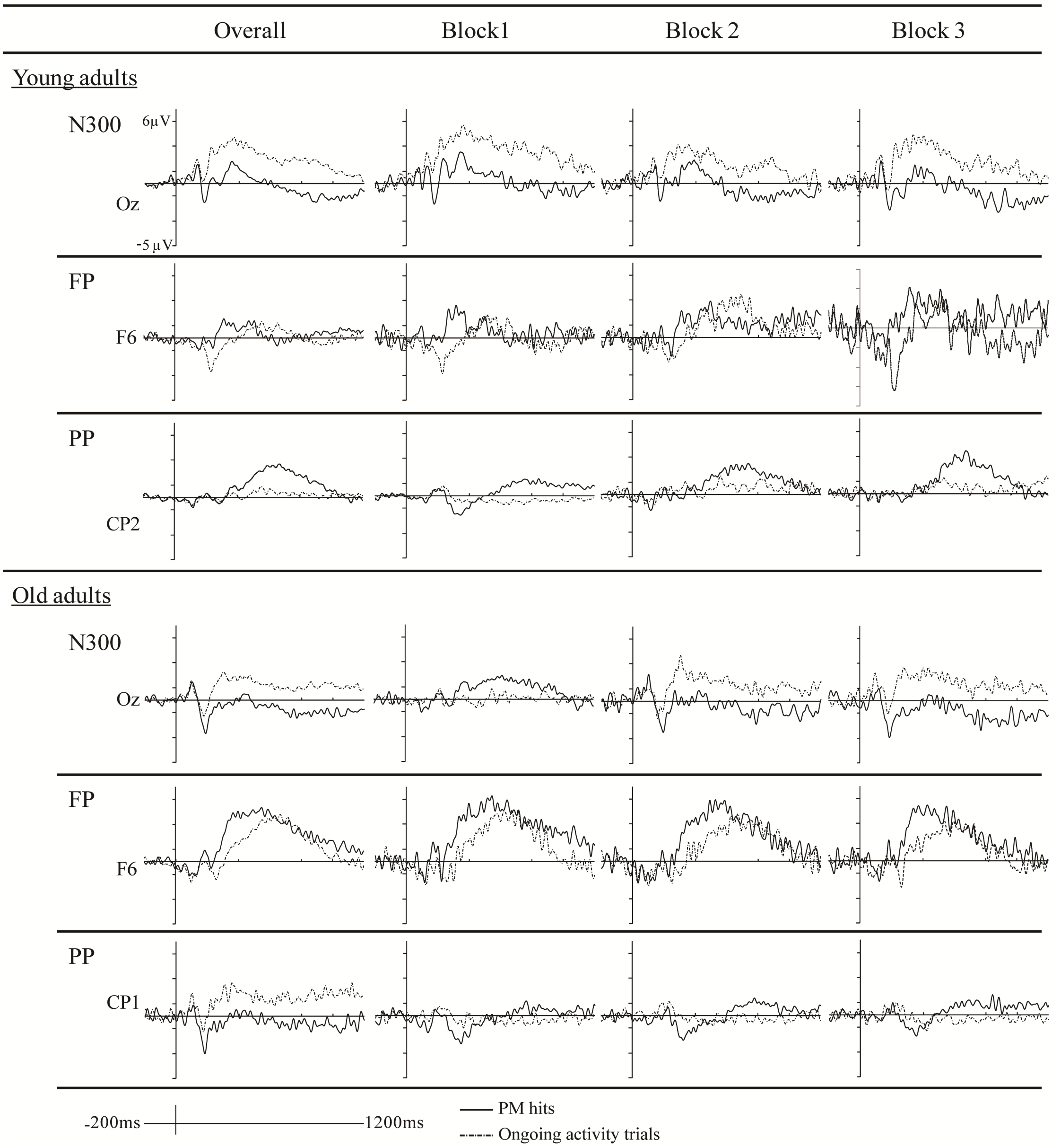

Figure 10. **The ERP's across all blocks and for each block separately.** Grand-averaged event-related brain potentials demonstrating the overall and the block specific N300 (electrode Oz), frontal positivity (FP, electrode F6) and parietal positivity (PP, electrode CP2 for young adults, electrode CP1 for old adults) for PM hits and ongoing activity trials in young and old adults.

Automatization effects. To check for automatization effects in the N300 amplitude we performed a 2 (condition: PM hits, ongoing activity trials) * 3 (block: 1, 2, 3) repeated-measures ANOVA. Most interestingly the interaction of condition × block was significant on a trend level, $F(2,44) = 2.77$, $p < .10$, $\eta^2 = .112$. This interaction indicates that from block 1 to block 2 the N300 does not change ($p > .10$, i.e. neither a change in ongoing activity trials nor in PM hits), but from block 2 to block 3 the N300 significantly increases ($p < .05$, i.e. no change in ongoing activity trials, significantly greater negativity in PM hits, see Figure 12). Furthermore, the analysis revealed a significant effect of block, $F(2,44) = 3.29$, $p < .05$, $\eta^2 = .130$.

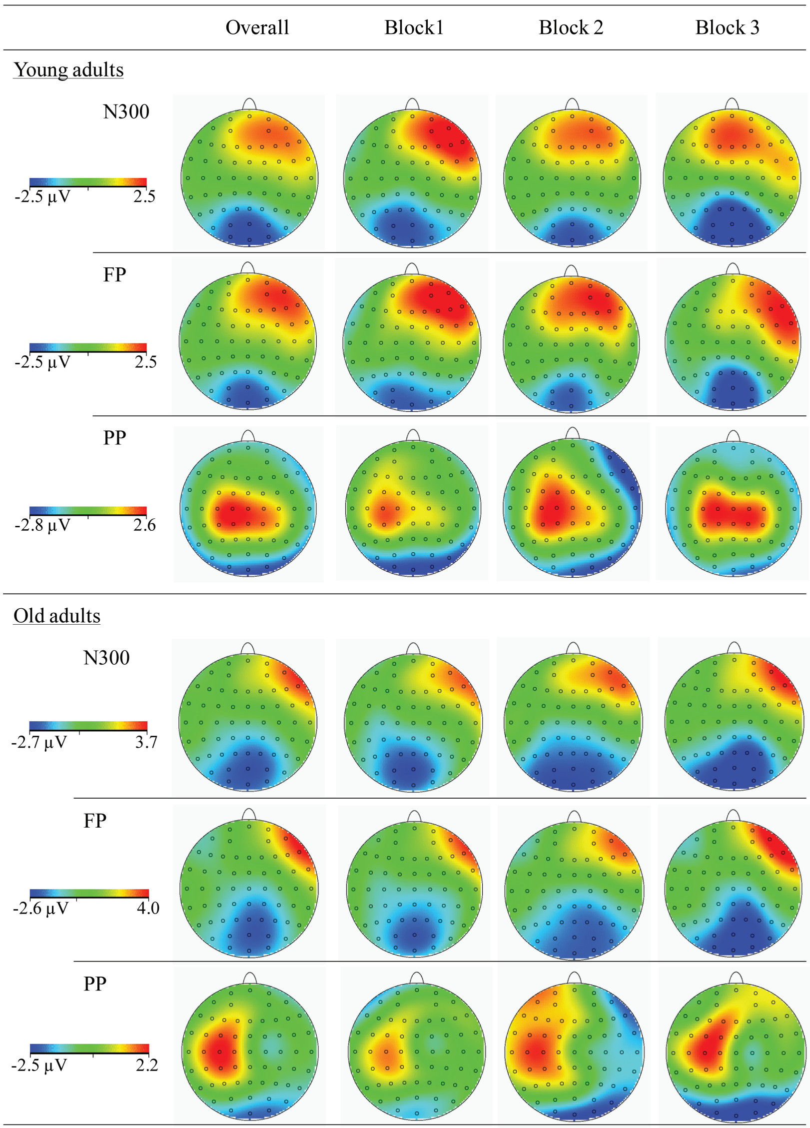

Figure 11. **Topographical maps.** Topographical maps depicting the difference between PM hits minus ongoing activity trials across the course from block 1 to block 3 in young and old adults. Blue indicates a negative difference (PM hits < ongoing activity trials) and red a positive difference (PM hits > ongoing activity trials).

Frontal positivity in young adults.

Overall. The 2 (condition: PM hits, ongoing activity trials) * 8 (electrodes: FP2, AF4, AF8, F4, F6, F8, FC6, FT8) repeated-measures ANOVA showed a significant frontal positivity, as the effect of condition was significant, $F(1,22) = 24.75$, $p < .01$, $\eta^2 = .529$ (PM hits > ongoing activity trials). Furthermore, the effect of electrode reached significance, $F(7,154) = 5.53$, $p < .01$, $\eta^2 = .201$, but not the interaction of condition × electrode $F <$, $\eta^2 = .068$. The frontal positivity was significant at each electrode (all ps < .01).

Automatization effects. The 2 (condition: PM hits, ongoing activity trials) * 3 (block: 1, 2, 3) repeated-measures ANOVA did not reveal any signs of automatization in the amplitude of the frontal positivity as neither the interaction of condition × block, $F < 1.00$, $\eta^2 = .020$ nor the effect of block were significant, $F < 1.00$, $\eta^2 = .005$.

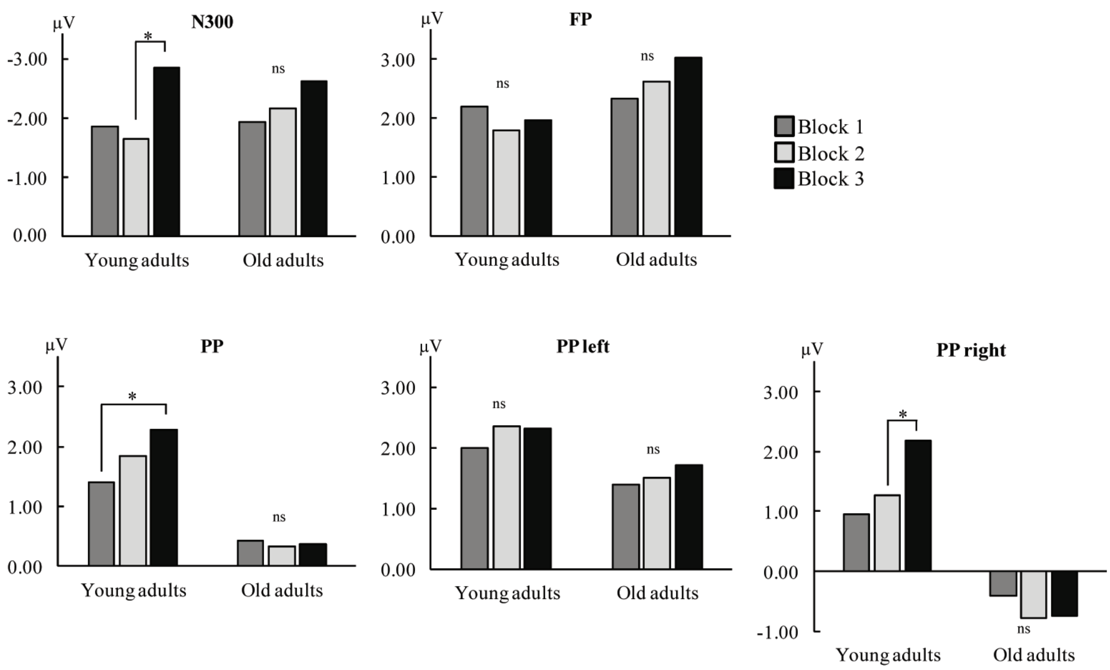

Figure 12. Mean components across blocks. Mean component size in the three blocks, representing the N300, the frontal positivity (FP) and the parietal positivity (PP) for young and old adults. Bars represent the mean difference between PM hits and ongoing activity trials. Arrows mark the significant changes, ns indicates a non-significant change across the three blocks.

Parietal positivity in young adults.

Overall. The parietal positivity in young adults measured with a 2 (condition: PM hits, ongoing activity trials) * 10 (electrodes: C1, Cz, C2, C3, C4, CP1, CPz, CP2, CP3, CP4) repeated-measures ANOVA resulted in a significant effect of condition, $F(1,22) = 43.87$, $p < .01$, $\eta^2 = .666$ (PM hits > ongoing activity trials) and of electrode, $F(9,198) = 4.17$, $p < .01$, $\eta^2 = .159$. The interaction of condition × electrode reached trend level, $F(9,198) = 2.22$, $p < .10$, $\eta^2 = .092$. The parietal positivity (i.e., the effect of condition) was, however, significant at each electrode (p < .01).

Automatization effects. In the 2 (condition: PM hits, ongoing activity trials) * 3 (block: 1, 2, 3) repeated-measures ANOVA, we found a marginally significant interaction of condition × block, $F(2,44) = 2.41$, $p = .10$, $\eta^2 = .099$, indicating an increase in the amplitude of the parietal positivity ($p < .10$) when comparing block 1 to block 3. Mean activity in block 2 lies between the early and late blocks, not reaching a significant difference to either ($p > .10$). Furthermore, the effect of block was significant on a trend level, $F(2,44) = 3.08$, $p < .10$, $\eta^2 = .123$.

Based on visual inspection of the topographical maps (see Figure 11), we performed additional analyses for the two hemispheres. We found, that the parietal positivity did not change across blocks over the left hemisphere, $F < 1.00$, $\eta^2 = .014$. However, over the right hemisphere, the effect of block was significant, $F(2,44) = 3.34$, $p < .05$, $\eta^2 = .132$, indicating no change ($p > .10$) in amplitude from block 1 to block 2, but a significant increase ($p < .05$) from block 2 to block 3.

N300 in old adults.

Overall. In old adults the 2 (condition: PM hits, ongoing activity trials) * 9 (electrodes: P1, Pz, P2, PO3, POz, PO4, O1, Oz, O2) repeated-measures ANOVA revealed significant effects of condition, $F(1,22) = 53.77$, $p < .01$, $\eta^2 = .710$ (PM hits > ongoing activity trials) and of electrode, $F(8,176) = 13.95$, $p < .01$, $\eta^2 = .388$. The interaction of condition × electrode was significant, $F(8,176) = 2.57$, $p < .05$, $\eta^2 = .104$. However, the N300 was significant at each electrode (all *p*s < .01).

Automatization effects. In old adults we did not find any changes in the amplitude of the N300 across the three blocks. Neither the interaction of condition ×

block, $F < 1.01$, $\eta^2 = .044$, nor the effect of block were significant, $F < 1.00$, $\eta^2 = .042$.

Frontal positivity in old adults.

Overall. The frontal positivity was significant in old adults as shown in the significant effect of condition, $F(1,22) = 40.64$, $p < .05$, $\eta^2 = .649$ (PM hits > ongoing activity trials). Furthermore, the effect of electrode and the interaction of condition × electrode were significant, $F(7,154) = 7.19$, $p < .05$, $\eta^2 = .246$ and $F(7,154) = 12.91$, $p < .05$, $\eta^2 = .370$, respectively. Nonetheless, the frontal positivity was significant at each electrode (all *p*s < .01).

Automatization effects. In old adults, we did not find changes in the amplitude of the frontal positivity across the three blocks. Neither the main effect of block, $F < 1.00$, $\eta^2 = .018$ nor the interaction of condition × block was significant, $F < 1.00$, $\eta^2 = .022$.

Parietal positivity in old adults.

Overall. For old adults the parietal positivity (i.e. the effect of condition) was only significant on a trend level, $F(1,22) = 3.02$, $p < .10$, $\eta^2 = .121$ (PM hits > ongoing activity trials). The effect of electrode and the interaction of condition × electrode were significant, $F(9,198) = 3.57$, $p < .05$, $\eta^2 = .139$ and $F(9,198) = 14.09$, $p < .01$, $\eta^2 = .390$, respectively. To follow up on this interaction, we performed – according to visual inspection of the topographic maps – separate analyses for groups of electrodes (right hemispheric: C2, C4, CP2, CP4, left hemispheric: C1, C3, CP1, CP3, and central: Cz, CPz). The effect of condition was significant for the left hemisphere, $F(1,22) = 32.46$, $p < .01$, $\eta^2 = .596$ (PM hits > ongoing activity trials). Over the right hemisphere, the effect of condition reached trend level, $F(1,22) = 3.28$, $p < .10$, $\eta^2 = .130$, but in the "wrong" direction (PM hits < ongoing activity trials). Over the central brain region, the parietal positivity was not significant, $F < 1.00$, $\eta^2 = .022$.

Automatization effects. In old adults, we did not find any indication for automatization effects in the amplitude size of the parietal positivity, as the interaction of condition × block was not significant, $F < 1.00$, $\eta^2 = .001$. The main effect of block was also not significant, $F < 1.02$, $\eta^2 = .044$. This remained even when performing separate analyses for the parietal positivity in the two hemispheres, left: $F < 1.00$, $\eta^2 = .011$, right: $F < 1.00$, $\eta^2 = .014$.

3.4.4. Discussion

This study was designed to examine to what extent behavioral and electrophysiological measures change in the course of multiple repetitions of a PM event. We looked at reaction times for PM hits and ongoing activity trials and the electrophysiological modulations of PM across blocks of early, middle, and late trials. Changes may be the result of higher accessibility and a strengthened association between a PM cue and its intention memory trace reflecting a transition to more automatic and efficient PM in young and old adults.

Results showed that for young adults reaction times in PM hits and ongoing activity trials changed from middle (trials 11-30) to a late block (trials 21-30). In both blocks reaction times for PM hits were shorter than for ongoing activity trials. Previous studies also found reaction times to be shorter for trials that are associated with a delayed intention (i.e., a PM cue) relative to ongoing activity trials (Goschke & Kuhl, 1993; Zöllig et al., 2007). This effect has been called *intention superiority effect* and reflects the enhanced activation or increased accessibility of intention relevant material, while adding task costs to the ongoing activity trials (Ellis & Freeman, 2008; Marsh, Hicks, & Bink, 1998; R. E. Smith & Bayen, 2004, 2006). One could argue that on early occasions of PM cue presentation, the activation of the intention relevant material is already enhanced leading to shorter reaction times in PM hits compared to reaction times in ongoing activity trials due to PM task costs in the latter and this was true for both young and old adults. However, in young adults the association between the PM cue and the intention is strengthened and thus the mental track to PM cue detection is paved after the successful completion of 20 PM trials (block 1 and 2). An increased accessibility of the intention memory trace leads to shorter response latency for PM hits in block 3. At the same time, the reaction time for the ongoing activity decreased to a higher degree (see Table 1), indicating a significant reduction in task costs. This reduced task costs may result in a further increase in the efficiency of the available attentional resources.

This interpretation is in line with our findings from the electrophysiological data on changes in the amplitude of the N300 in young adults. Based on the assumption of an inverse relation between the allocation of controlled attentional resources and the amplitude of the N300 (West, 2011), the increase in the N300 amplitude from block 2 to block 3 in young adults may indicate less allocation of controlled attentional processes to detect the cue. The elevated amplitude may, thus, reflect more efficient cue-detection that needs less attentional resources or, in other words, a higher automaticity in detecting a PM cue.

The fact that we did not find any changes in the young adults' amplitude of the frontal positivity across the three blocks may indicate that although attentional resources to detect the cue became more efficient and therefore less required across blocks (N300 increase), the ability to switch the attention from the PM to the ongoing task still requires the same amount of resources. This result matches the finding that reaction times as a correlate of improved task switching did not consistently change in young adults as result of cognitive load (West et al., 2006). Hence, the herein reported decrease in reaction time from block 2 to block 3 in young adults seems not to be the result of more efficient switching mechanisms but instead more likely to represent higher efficiency of attentional mechanisms related to cue-detection.

Against our prediction, we found an increase in the parietal positivity of young adults over the right hemisphere. As the modulations that represent intention retrieval and prospective task set have been found not to be influenced by the availability of attentional resources (West, Herndon et al., 2003), our result may indicate a considerable P3 contribution to the parietal positivity. In the past, there has been evidence suggesting that generally less mental demand and thus less attentional resource allocation leads to increased P3(b) amplitudes (Kok, 2001). Thus, the variation in attentional resource allocation across the three blocks of our experiment may have influenced the P3 amplitude of young adults and thus the parietal positivity. There is evidence showing that the amount of P3 contribution of the parietal positivity depends upon the perceptual characteristics of the PM cue (West, Wymbs et al., 2003). According to the description of salience of a PM cue as "unusual relative to prior knowledge or distinctive relative to the existing context" (McDaniel & Einstein, 2000, p. 134), we would not have labeled our cue as salient; nevertheless, it might be that the cue color itself (magenta) was rather salient. Future studies might want to use different colors for their cue to exclude this possibility. Another possibility might be that for young adults, the cue salience changed across trials from being non-salient in the beginning to becoming more and more salient towards the end of the experiment. This possibility is in line with the model of Schneider and Shiffrin (1977) proposing that an attention response that directs the attention automatically becomes difficult to suppress or ignore once it has been automatized.

In old adults, neither reaction times nor amplitude size of the N300, frontal positivity, or parietal positivity changed across the course of 30 PM hits or across 30 ongoing activity trials. Following our conclusion from young adults, this may indicate that, although we had a very fit and high-performing group of old adults, they did not show any signs of automatization of PM across 30 trials. For old adults, it is hence necessary to constantly activate a high amount of attentional resources to successfully complete a PM task even after a considerable amount of PM hits has been achieved. Constant activation of a high amount of attentional resources might be overly demanding and thus cognitively exhausting (Einstein & McDaniel, 2005). Furthermore, previous research described old adults' attentional resources to generally be less efficient (Glisky, 2007), which leads to an even greater amount of precisely those attentional resources needing to be allocated to achieve the required amount to correctly execute a PM tasks. The combination of less efficient attentional resources and failed/missing automatization might represent part of the reason why older adults are often found to achieve lower PM performance compared to young adults.

Whether PM really becomes fully "automatic" ("spontaneous" in the sense of the multiprocess framework (McDaniel & Einstein, 2000) not requiring any attentional effort) cannot be conclusively answered based on the results of our study. However, in contrast to the behavioral accuracy analyses conducted by Ellis et al. (1999), our reaction time and electrophysiology analyses could show that in young adults a certain amount of automatization arises after the repetition of PM cues. This does not necessarily mean that strategic control processes no longer play a critical role, but they might be needed to a more limited degree in order to complete the task successfully. As Hasher and Zacks (1979) have already remarked, the attentional requirement of mental operations is a continuum. Moreover, Burgess, Gonen-Yaacovi and Volle (2011) point out that it is currently a matter of debate whether complex cognitive functions such as PM can be fully "spontaneous" at all. Future research should therefore combine analyses of task costs (R. E. Smith & Bayen, 2004, 2006) and automatization effects to gain knowledge about remaining amounts of strategic control processes after automatization. Furthermore, it would be interesting to test to what degree automatization can be expanded – similar to a "testing the limits" approach (e.g., Kliegl, Smith, & Baltes, 1989) – and what effect this would have upon the electrophysiology of PM.

Another clear limitation of the current study is the selective sample of cognitively fit old adults, as we applied the selection criterion of at least 30 PM hits to be able to distinguish the paradigm into three blocks and create event-related potentials with an acceptable signal-to-noise ratio. Future studies might want to try to overcome this by applying other types of analyses such as single-trial analyses (e.g., Delorme & Makeig, 2004) of the event-related potential or spectral analyses that are restricted to some narrow frequency-bands (e.g., Sauseng et al., 2006).

Nevertheless, our study could show that even in cognitively fit old adults no signs of automatization occurred for this amount of repetition, leading to the assumption that in less fit old adults the chance would be very low to find any such signs. However, it might be interesting for future studies to analyze whether it would be possible to induce automatization in old adults through a greater number of repetitions or a specific training (Glisky, 2007), as it has been done in other field of cognitive research (e.g., Kramer, Larish, Weber, & Bardell, 1999). As shown in this study, a suitable measure of training induced automatization seems apparently to be at hand. The development of automatic processes might prevent from overloading our limited capacity system (Hasher & Zacks, 1979). Additionally, by achieving automatization in old adults, PM accuracy might be enhanced as a result of less cognitive exhaustion due the continuous demand of strategic controlled mechanisms in old adults (Einstein & McDaniel, 2005).

To sum up, the goal of this study was to analyze whether PM retrieval does show automatization processes as a result of multiple repetitions of a PM task. We therefore measured changes in reaction times and in the electrophysiological signal of the brain associated with PM retrieval. Our results provide evidence for increasing efficiency and thus automatization in PM cue-detection in young adults but not in old adults as a consequence of repetition.

4. GENERAL DISCUSSION

In the overarching intentional behavior and goal attainment model (see Figure 1), I proposed that cognition, and more precisely prospective memory, constitutes an important instrument to successfully execute intentions and thus to reach superordinate goals across the lifespan. In this thesis, I presented three empirical studies, each addressing a different aspect of prospective memory performance and its development. In this final chapter, I will now (in points 4.1 - 4.4) simply summarize the main findings and try to very briefly answer the research question as formulated in chapter 2. Next (in point 4.5), I will discuss and integrate these findings in a broader context, and finally give a brief outlook on promising future research questions.

4.1. Summary of study I: Prospective memory performance across the lifespan and the relative contribution of different components

Prospective memory performance follows an inverted U-shaped function across the lifespan. However, the findings on the relative contribution of the two broad components, that is the prospective and the retrospective component (Einstein & McDaniel, 1996; McDaniel & Einstein, 2007), to this "rise and fall" are ambiguous. The first aim of study 1 was thus to measure prospective memory performance across the lifespan and replicate the finding of the inverted U-shaped function. We therefore had a sample consisting of 99 participants between 7.5 and 83 years of age divided into six age groups (young children, old children, young adults, middle-aged adults, young-old adults, and old-old adults). The second aim was to assess age-related changes in the prospective and retrospective component of prospective memory across the six age groups. The paradigm of this study was designed to control for the influence of the two components of our task with two specific but interrelated tasks: the "ordinary" *prospective memory task*, requiring the successful integration of both components, and a *retrospective component task* (consisting of two subtasks), assessing only the knowledge of the intention content (intended action and retrieval context) upon explicit request (see p. 25 for a detailed description of the paradigm). Also with regard to the second aim, we analyzed the developmental trajectory of the "prospective component error rate", that is, sequences in which participants correctly remembered the intention content upon explicit prompting in the retrospective component task, but did not initiate and execute the prospective memory task by themselves (i.e., execute the prospective memory trial).

Results confirmed the inverted U-shaped function of performance in the prospective memory and the retrospective component task across the lifespan. However, performance in the prospective memory task significantly interacted with performance in the two retrospective component subtasks, indicating differential trajectories from middle to old adulthood. In both tasks, performance increased from young to old childhood. In the prospective memory task, young-old adults already showed reduced performance that further declined in old-old adults. In contrast, performance in the retrospective component task (in both subtasks) was not reduced until old-old adulthood. Moreover, the performance level in the retrospective component task was very high across all age groups (89.9%[7] correct), also in young children (83.4% correct), and old-old adults (75% correct). Additionally, analyses of the "prospective component error rate" revealed a U-shaped function across the lifespan that matched the findings of the prospective memory performance in a mirror-inverted way.

Based on these results, we concluded that the functionality of both components seems to increase from young to old childhood and to decrease from middle-aged adulthood to old age. However, the prospective component seems to decline earlier in life than the retrospective component.

As the prospective memory task and the retrospective component task occurred in randomized order across sequences within the paradigm, we were furthermore interested in possible (positive or negative) rehearsal effects. Thus, the third question in study 1 aimed at analyzing these effects of intention content rehearsal across the six age groups. We speculated that correct recall of the intention content through the retrospective task might serve as a positive extra-rehearsal if preceding the prospective memory task, thereby boosting performance in the latter. However, results were converse to our expectation: performance in the prospective memory task was lower in those sequences in which a correct retrospective

[7] Mean of RM letter and RM color, because they did not differ significantly.

component task preceded (compared to those sequences in which the retrospective component task followed the prospective memory task).

With respect to negative rehearsal effects, we found – not very surprisingly – that a failure in the retrospective component task led to significantly lowered prospective memory performance if preceding as compared to following in all age groups. This result potentially reflected an intrusion effect. Intrusion effects are defined as inappropriate repetitions of prior responses (Shindler et al., 1984).

To sum up, the answer to research question 1 is the following: prospective memory performance follows an inverted U-shaped function across the lifespan, and it is mainly the prospective component within prospective memory that determines the trajectory and not failures of memory for the intention content.

Based on these results we concluded that the examination of the phases of intention-initiation and -execution (i.e., the retrieval interval) might lead to better understanding of the developmental path. Accordingly, the retrieval interval underwent a more detailed examination in study 2.

4.2. Summary of study II: Differences in the temporal dynamics of successful and failed prospective memory retrieval

The second empirical study in this thesis aimed at finding the root for prospective memory failures in the temporal course of the retrieval interval with all its subphases (see Figure 2) in selected developmental samples.

From a theoretical point of view and also with behavioral studies, the four phases of prospective memory (intention-formation, -retention, -initiation, and -execution) can be separated. Beyond that, previous research has shown that by using EEG to measure the brain's electrophysiological activity during the prospective memory retrieval interval, it is possible to distinguish different subphases. Thus, the second empirical study used event-related brain potentials (ERPs) to examine the development of the neural correlates associated with these subphases, that is the detection of a prospective memory cue, switching from the ongoing activity to the prospective task, and retrieval of the intention content from memory. Moreover, we analyzed ERP's related to strategic monitoring of the environment. The study included 99 participants between the age of 7.5 to 83 years divided into three age groups (children, younger adults and older adults).

In successful prospective memory trials, we found the components of the ERPs related to cue-detection (N300), switching (frontal slow wave), and task configuration (parietal positivity) were reliable across the lifespan. This might indicate that similar processes contributed to successful prospective memory performance at all ages. Differences occurred in terms of the temporal root of prospective memory failures. In children, errors seemed to be the result of a decoupling of processes supporting cue-detection and switching from the ongoing activity to the prospective memory task. By contrast, in younger and older adults, prospective memory errors appeared to result from a failure to detect the prospective memory cues in the environment. Moreover, results revealed that the electrophysiological activity related to strategic monitoring preceding successful prospective memory trials was reliable across the lifespan. This suggests that people from all age groups allocated attentional resources to facilitate prospective memory.

With respect to the second research question of this thesis (see 2.2), these results could show that the error to execute a prospective memory task happens at different stages of the retrieval interval in children and adults: children fail to switch, whereas adults do not detect the cue.

4.3. Summary of the analyses with respect to the electrophysiology during the intention-formation phase

In the form of an addendum, I presented supplementary analyses with respect to the electrophysiological activity during the intention-formation phase of study 2 (see 3.3). To successfully perform a prospective memory task, all phases have to be successfully paced. In study 2, we only presented results with respect to the retrieval interval, that is the intention-initiation and -execution phases of the prospective memory process. However, the question poses itself whether the failure occurred in this interval or whether the starting point lay within the intention-formation phase. With this question in mind, I performed supplementary analyses. The aim was to analyze whether there was a subsequent memory effect occurring during intention-formation trials. Previous research has shown that for both young and old adults components of the event-related potential can be observed that differentiate between subsequent prospective memory hits and subsequent prospective memory misses (West, Herndon et al., 2003; West & Ross-Munroe, 2002). However, in our data set, I did not find any of these components to significantly differentiate between later hits and later misses in any of the age groups. Based on these findings, one must conclude that the failure to switch between the ongoing activity and the prospective memory task (in children) or to detect the prospective memory cue in the environment (in young and old adults) is not grounded in a specific (erroneous) intention-formation.

To sum up, these supplementary analyses with respect to the intention formation phase further substantiate the conclusion drawn in study 2, namely that different processes occurring within the retrieval interval are the reason for failure in both children and adults.

4.4. Summary of study III: Automatization of event-related prospective memory retrieval across adulthood

The third empirical study presented in this thesis focused on one of the paradigmatic factors proposed within the framework of the intentional behavior and goal attainment model: attention allocation. Previous research is missing direct analyses of changes of resource allocation within subjects throughout the course of an experiment with respect to the question of automatization. Two behavioral studies that could be considered with respect to this topic have been described in chapter 1 of this thesis (McDaniel et al., 2009; McDaniel et al., 2008). The study by McDaniel et al. (2009) used a time-based prospective memory task. This type of prospective memory task is proposed to be more resource-demanding (d'Ydewalle, Bouckaert, & Brunfaut, 2001) and might thus allow less automatization to occur. Accordingly, only the results of Experiment 2 in the study of McDaniel et al. (2008) could be taken as indication for changes in resource allocation, as it revealed decreasing costs of the prospective memory task across the experiment. Studies from related fields of cognitive research have shown that the amplitude of ERP-components in young adults declines as a function of decreased effort required and increased automatization. ERP-analyses hence appear to represent an appropriate method for analyzing this question. Accordingly, the current study investigated effects of automatization across 50 identical prospective memory events on reaction times and ERP-components in young and old adults.

Results revealed that young adults showed signs of automatization in reaction times and the electrophysiology associated with cue-detection (i.e., the N300) in the course of repetition of the prospective memory task. Furthermore, the findings suggested that attentional resources to detect the prospective memory cue became more efficient with increasing repetition. We argued that the enhanced efficiency appears to be the result of a strengthened association between the prospective memory cue and its intention memory trace due to repetition. By contrast, old adults apparently did not automatize prospective memory reactions within this limited amount of repetition. We concluded that the combination of decreased efficiency of attentional resources in old adults with absent (or at least delayed) automatization might reflect two of the underlying reasons for reduced prospective memory performance of old adults.

To sum up, research question 3 of this thesis (see 2.3) can be answered as follows: in young but not in old adults, the cognitive functions that support prospective memory retrieval change across the repetition of a prospective memory cue insofar as the attentional effort to detect the cue decreases.

4.5. Discussion and potential future studies

In this section I will discuss a selection of the previously described results in a broader manner and integrate the three studies of this thesis. For the discussions of the complete results, the interested reader is referred to the discussion sections of the empirical studies. The section is structured according to different thematic lines of thinking, each starting from the empirical results from the studies described above, followed by open questions and suggestions for future studies.

4.5.1. Intrusion effects and a tension hypothesis

In study 1 we found – regardless of the individual's age – intrusion effects of incorrect intention content retrieval on subsequent prospective memory task performance. That means that an erroneous repetition of the intention content through a preceding retrospective component task lowered subsequent prospective memory performance. Given this finding, one question obviously arises: what effect does the correct repetition of the intention content by a preceding retrospective component task have upon subsequent prospective memory performance? We speculated that in cases of successful intention content rehearsal something similar to “intrusion effects” may also occur, but in a positive way, reflecting an extra-rehearsal. This extra-rehearsal could then boost subsequent prospective memory performance.

An early study by Guynn et al. (1998) has shown that reminders that referred to both the intended action and the retrieval context did improve subsequent prospective memory performance. However, as results of study 1 showed, this was not the case in our study. The results of study 1 with respect to effects of order showed that irrespective of the retrospective component task’s accuracy, performance in the prospective memory task was lower in sequences in which the retrospective component task preceded. In this context, one topic that has been touched on was the tension that an intention produces in the individual. Already Kurt Lewin stated in his seminal work “Intention, Will, and Need”[8] that “there exists […] an internal tension-state which presses to carry out the intention” (as cited in McDaniel & Einstein, 2007, p. 83).

Within this theoretical context exists one line of prospective memory research that argues that intended actions are stored in memory in a state of higher activation (i.e. more tension) than other memory contents (Goschke & Kuhl, 1993; Marsh et al., 1998). This higher state of activation enables fast and easy access to the intention content and thereby increases the chance of being executed when the appropriate retrieval context is detected. This implies that once an intended action is executed, the tension gets released, with the higher activation no longer needing to be maintained. More extra-activation is now necessary to reinitiate the intention (McDaniel & Einstein, 2007). This theoretical background might help to explain the findings in study 1. Our experiment was specific with respect to paradigmatic factor c) intention alteration (see Table 1): each of the 33 sequences started with the formation of a new (one out of four possible) intention consisting of a combination of retrieval context and action. This means that the tension for one specific intention should only be held for a limited time, that is to say until both the retrospective element and the prospective memory task of one sequence have been executed. Then the tension for a new intention must be set up during the intention-formation phase of

[8] Vorsatz, Wille und Bedürfnis (Lewin, 1926)

the next sequence. The replacement of the intention allows for the release of the tension of one intention (i.e., the executed one) and the setup of the tension for the new intention. However, it is possible that once participants answered the retrospective component task (i.e., actively indicated the color and action of their intention after an explicit prompt) the tension was released because part of the intention, that is remembering the color and the action, was executed, despite not being self-initiated (as in actual prospective memory trials), but upon explicit prompting. As a consequence of the partly released and thus no longer strong-as-necessary tension, accuracy in the following prospective memory trial, that is when the intention should have been self-initiated upon cue-detection, was lowered. The other way round, that means if the prospective memory trial preceded the retrospective component task, this effect did not occur because the explicit prompt served as by far enough extra-activation to again recall the intention content. The conflicting results between Guynn et al. (1998) and our study may thus be due to two paradigmatic peculiarities: for one, the fact that in our paradigm participants having to actively indicate the intention content (by actively pressing buttons) may have been sufficient to release the tension. In contrast, in the study by Guynn et al. participants were only verbally reminded “to not forget to…”. This purely verbal and from the participant’s perspective “passive” reminder (i.e., the participants themselves did not *do* anything) might not have led to a tension release but instead have increased the tension through higher activation and thus boosted the subsequent performance. Second, the different experimental conditions with respect to the paradigmatic factor c) intention alteration reflected another difference between our and the Guynn et al. study. In the latter, participants had to hold the same intention content across the whole experiment. The tension for this intention had accordingly to be held throughout the entire experiment. Again, in our study, the intention and thus the tension had, in contrast, to be renewed in every sequence.

Future research projects may want to analyze this tension hypothesis more closely by trying to specifically address the following research question: *what effects do reminders and/or rehearsal of the intention content have upon the intention-based tension within an individual?*

Personality traits within the tension hypothesis

Another aspect within the tension hypothesis concerns the role of the interaction between cognition and the other instruments that contribute to successful intentional behavior (see the intentional behavior and goal attainment model in Figure 1). It seems plausible to assume that the amount of tension that an intention creates is determined by the interaction of the prospective memory capability and factors such as personality traits and social aspects like social pressure. It has been shown that, for example, more conscientious people perform better in prospective memory tasks (Cuttler & Graf, 2007). This can be explained given that the defining factors of conscientiousness are for example following prescribed norms, being task- and goal-focused, and being planful (Bogg & Roberts, 2004). Based on the proposed hypothesis, one could speculate that the mechanism behind that finding is that intentions produce stronger tension in people with higher conscientiousness and are thus more reliably executed. The exact relation between personality traits in general and conscientiousness in detail and the tension-approach of prospective memory holds great potential for future studies. The consequent research question would be: *how do differential personality traits moderate prospective memory performance and what role does intentional tension play in this relationship?*

4.5.2. The source of failures

The second study within this thesis offered an answer to the question about *when* and due to what underlying process errors occur within the prospective memory retrieval interval. Nevertheless, it is beyond the scope of the results of study 2 to answer the question about the source of the failures within the retrieval interval. In other words, the open question is: *why* do these failures occur as they assumedly occur, with failed switching in children and failed cue-detection in adults? In regards to the prospective memory process, two phases temporally precede the retrieval interval and thus may represent the starting point of the failures in the retrieval interval: the intention-formation phase and the intention-retention phase (see Figure 2). The possibility that the failures are predetermined by specific processes occurring during the intention-formation phase appears less probable when bringing in the supplementary results presented under point 3.3 of this dissertation. These results revealed that the electrophysiology during the intention-formation phase showed no indices for subsequent success or failure. The results from study 1 further substantiate this finding: participants from all age groups mostly (with 89.9% frequency) remembered the intention content when explicitly asked about it. This means that apparently they have encoded the intention content (action and retrieval context) properly even in a great part of cases of subsequent failures on the prospective memory trials. As argued in study 1, the failure to execute the intention successfully was most often not due to a failure of remembering the intention content, but instead due to the failure to autonomously initiate the intention. Clearly, it remains speculative, but as it appears on the basis of these data, the intention-formation phase within our paradigm was not the point of origin for failures and thus not the reason why children failed to switch and adults failed to detect the cue.

With respect to the intention-retention phase as a potential starting point for the failures in the retrieval interval, the current evidence is less clear. Electrophysiological data of study 2 revealed that strategic monitoring preceding prospective memory hits did not differ across the age groups. This indicates that during retention phases that precede prospective memory *hits*, people from all age groups used strategic monitoring similarly. However, due to methodological reasons, we currently do not have data about strategic monitoring preceding prospective memory *failures* in the data set. The question thus remains unanswered with respect to processes during the intention-retention phase that differentiate between subsequent successful or failed prospective memory performance. Hence, the systematic exploration of these processes clearly deserves future elaboration with specifically intention-retention phase aligned designs. One potential suggestion for a research question would be: *do specific processes during the intention-retention phase determine subsequent prospective memory performance and do they differ across the lifespan?*

4.5.3. Disuse of expedient resources in old adults and children

The integration of the results of study 1 and 2 with respect to successful prospective memory trials revealed a puzzling effect. We found clear evidence for prospective memory performance following an inverted U-shaped function across the lifespan; broadly speaking we found increasing performance during childhood and decreasing performance towards old age. Furthermore, study 2 showed that the temporal dynamics of underlying prospective memory failures differ between children and adults, but not between young and old adults. In brief, children fail to switch from the ongoing to the prospective task, whereas young and old adults fail to detect the cue. At the same time, the electrophysiological correlates related to successful prospective memory trials (as well for strategic monitoring and for retrieval) did not differ across the lifespan. Thus, from our data the following conclusion seems warranted: *if* participants *fail*, different processes are responsible in children and adults. But *if* they are *successful*, similar electrophysiology can be found, regardless of the participants' age. But again, the amount of prospective memory hits varies across the lifespan. In other words, while children and older adults do allocate – meaning they are able to allocate the same processes to successfully answer a prospective memory task as young adults – they do so significantly less often.

So the question now arises: why does this happen? Why is it that children and older adults less often allocate these "success-bringing", expedient resources that they obviously do possess and are able to use? With the results of study 1 and 2, this question cannot be answered. However, at least with respect to old age, results of study 3, together with an additional analysis, shed some light onto this ambiguity and at the same time open the field for further considerations.

Resource allocation in young and old adults

As reported in study 3, there was a clear difference in the progress of electrophysiological activity (most notably in the N300) between young and old adults, indicating a change of resource allocation in young but not in old adults. This change of resource allocation that we interpreted as sign of automatization may represent the reason for the previously described ambiguity. As we argued in the discussion of study 3, failed automatization and thus prolonged need for effortful resource allocation may be cognitively exhausting (Einstein & McDaniel, 2005). As a consequence older adults may (or may be able to) allocate these resources less often (I will come back to this point below).

This finding represents the result of a different methodological approach: we divided one measurement occasion into separate blocks. These blocks could then be compared within one group. That way, this one measurement occasion turned into a "mini-longitudinal design" as it involved repeated observations of the same variable within the same subjects over time. For a better illustration of this strength of study 3, I performed an additional analysis with respect to the N300[9]. As in previous EEG-studies (e.g., Bisiacchi et al., 2009; West & Krompinger, 2005; Zöllig et al., 2007, and also in study 2), I averaged across all available trials (across all prospective memory hits and across all ongoing activity trials preceding prospective memory trials) and compared these "overall grand-averaged ERP's" between young and old adults. This analysis revealed similar "overall N300 amplitudes" for young and old adults[10]. Hence, with this commonly-used approach to the analyses (averaging across all available trials and cross-sectional comparison), an interesting difference in the way that young and old adults accomplish a prospective memory task would have been obscured.

The methodological approach of study 3 thus seems to represent a promising key to the deeper understanding of prospective memory. Future studies might expand on this methodological approach by combining multiple such mini-longitudinal measurement occasions, for example before and after a cognitive intervention with older subjects. This might lead to more knowledge about potential plasticity of prospective memory. As prospective memory represents an important ability within the context of intentional behavior and, further, for goal achievement (see Figure 1) up to old age (e.g., for medical adherence, Liu & Park, 2004), it seems reasonable to aim at stabilizing its functionality under any kind of paradigmatic configuration.

Plasticity of prospective memory in old age I: A SOC-approach

As I mentioned in the introduction, assumedly the functionality of this conglomeration of executive functions and episodic memory that represents prospective memory as it is understood in this thesis declines in the everyday life of older people (G. Smith, Della Sala, Logie, & Maylor, 2000). However, as a consequence of the interaction of prospective memory with motivational factors, social aspects, personality, and others, aging people on the one hand develop specific

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[9] These additional analyses are not reported in the study itself

[10] Interaction of group (young, old) × trial (prospective memory hits, ongoing activity trials, $F < 1.00$, $\eta^2 = .000$.

strategies to circumvent these potentially emerging deficits in prospective memory performance (having post-it notes all over, setting the alarm clock for different things, making to-do lists, etc.). On the other hand, as mentioned in the introduction, older people's intention-retention phase seems to be less filled with "everyday business" (Phillips et al., 2008). These two lead to the previously mentioned "age-prospective memory paradox" (Rendell & Craik, 2000).

In this section, I would like to consider this phenomenon within the theoretical framework of the model of Selection, Optimization and Compensation (SOC, Baltes & Baltes, 1990). The model proposes that by orchestrating the three components (SOC), limitations in resources can be mastered adaptively across the entire lifespan (Freund & Baltes, 1998). The strategies that people develop to circumvent failures of prospective memory tasks such as the previously mentioned external memory aids can be seen as compensational mechanisms, as they represent substitutive processes to maintain the level of functioning. Moreover, two findings may represent the result of selective means. First, a reduction of activities that are performed during the intention-retention phase of the prospective memory process (Phillips et al., 2008) can be regarded as a selection that older people carry out (Freund & Baltes, 1998). Second, the previously mentioned interpretation that older adults less often engage in exhausting resource allocation could be the result of selection (see above under "Resource allocation of young and old adults"). That is, instead of investing only few attentional resources across the whole experiment and as a consequence failing in the prospective memory task, older people focus on completing a limited number of prospective memory trials successfully by allocating all of the remaining resources selectively.

Nevertheless, it seems plausible to assume that at a certain level of limitation in resources or demand upon the resources, these compensatory and selective means will no longer be sufficient for successful prospective memory performance and thus on the long run will endanger an autonomous life. At this point automatization may become important as a form of optimization. Optimization is defined as "the allocation and refinement of internal or external resources as means of achieving higher levels of functioning in selected domains" (p. 531, Freund & Baltes, 1998). The increase of the efficiency of attentional resources by means of automatization that we found in young adults can accordingly be regarded as optimization strategy. Apparently, automatizing the prospective memory response reflected more efficient resource allocation and thus less demand of attentional resources (the higher the efficiency, the less are needed). As a consequence, it may be assumed that if old adults would be able to automatize prospective memory successfully, their decreased attentional resources might still be sufficient and thus age-related decrease would be reduced. Hence, future studies should try to find ways to activate automatization in older adults, as from a theoretical point of view it seems to represent a promising instrument to stabilize performance despite less attentional resources being available.

Plasticity of prospective memory in old age II: An implementation intentions-approach based on the multiprocess theory

Another approach to understand the results of study 3 represents the multiprocess theory of prospective memory (McDaniel & Einstein, 2000). In brief, this theory proposes that automatic as well as strategic, resource-demanding processes can be targeted for prospective memory tasks. As the automatic associative model of prospective memory (Guynn et al., 2001; McDaniel et al., 1998), the multiprocess theory predicts that an automatic prospective memory response is possible if the cue produces a strong enough interaction with the memory trace of the encoded intention. Such an interaction activates the associative system, which rapidly, obligatorily and with few attentional resources delivers the intention content to consciousness (McDaniel & Einstein, 2000). Generally cognitive functions which rely on automatic processes have been reported to be less affected by increasing age (e.g., Jennings & Jacoby, 1993). This is also true for prospective memory performance, which relies on automatic cue-detection from the beginning, that is for example with very focal and salient cues (McDaniel et al., 2008). The interesting question with respect to the current work thus is: how can the transition from effortful, attention-demanding to more automatized prospective memory responding be boosted in older adults under any kind of paradigmatic factor configuration? Or in other words, how can the interaction between the cue and the memory trace of the encoded intention in old adults be tightened, so that less attentional resources are required? Once automatized, prospective memory performance should be less affected by negative age effects. Automatization thus appears to reflect a promising approach for stabilizing prospective memory throughout old age.

In the discussion of study 3 we proposed that increasing the number of prospective memory trials and thus generating more instances of activation of the cue-intention-association might be one potential starting point for fostering automatization in old adults. Another approach for promoting automatization in old adults that I would like to suggest is the intention-formation or -encoding phase. Related to that idea, Chasteen, Park and Schwarz (2001) and Zimmermann and Meier (2010) showed that the use of implementation intentions can help improve prospective memory performance in older adults. Implementation intentions describe the act of *explicitly imagining* a detailed plan of how one will initiate the intended action when encountering the cue in the environment (Gollwitzer, 1993). The detection of the cue then automatically triggers the initiation and execution of the intended action by establishing a sensitivity to the environmental cue and thus reducing the need for continued attentional resource allocation (A. L. Cohen & Gollwitzer, 2008; Park, Gutchess, Meade, & Stine-Morrow, 2007). The instruction to create an implementation intention might thus promote the transition from effortful, attention-demanding prospective memory to more automatized prospective memory in older adults. Thereby it could help to stabilize or even improve prospective memory performance throughout old age without the use of external memory aids such as post-its, alarm clocks and so on. To be clear, I am not proposing that young adults obligatorily and intrinsically create implementation intentions and thus automatize faster whereas older adults do not. Instead, I propose that as older adults are known to associatively bind items less efficiently in general (the associative deficit hypothesis, Naveh-Benjamin, 2000), it might be particularly fruitful for old adults to use this "association-boosting" act of creating implementation intentions.

Overall, as can be inferred from the discussion above, the following research question remains open and needs further investigation: *is it possible to generally activate or promote automatization of prospective memory performance in old age to stabilize performance for example by instructing seniors to use implementation intentions?*

Resource allocation in children

We found ambiguity not only in older adults but also in children, with the same electrophysiological activity noted during successful prospective memory performance but with lower levels of performance. Because we did not include children in study 3, we currently have no data at hand that might explain this and hence the question remains why children less often allocate the "success-bringing" resources that they obviously do possess. In the following section I will nevertheless speculate about a potential starting point for overcoming this ambiguous effect.

Plasticity of prospective memory in children: An implementation intentions-approach based on the multiprocess theory

According to the multiprocess theory, focal and salient cues activate automatic cue-detection (McDaniel & Einstein, 2007) and in this way reduce age-related effects. Similar as in aging studies, it has been found that age-related differences in prospective memory performance in younger and older children are smaller if the cue is focal and if the cue is salient. That means that children are theoretically able to automatically execute prospective memory tasks. However, with respect to the open question about the reason for less frequent input of the expedient resources in children, it is so far unknown *whether* and if so *when* children do or can automatize throughout the progress of an experiment as young adults do. If following the logic above, given that children are theoretically able to automatically perform a prospective memory task, one possibility to foster a transition from resource-demanding to automatic prospective memory responding might also lie in the use of implementation intentions. As I argued above, implementation intentions strengthen the association between a cue and the intention content and might thus enable more automatized (i.e., less resource demanding) prospective memory responding. A meta-analysis conducted by Gollwitzer and Sheeran (2006) revealed that implementation intentions generally (i.e., not specifically for prospective memory tasks) seem to evoke similar effects in children and in healthy (young) adults. Moreover, a prospective memory study by Zimmermann and Meier (2010) revealed that adolescents (they have no data for children either) profited at least as much from implementation intentions as young adults did. Accordingly, children seem to similarly benefit from strengthening the association between cue and intention content as young adults.

Hence, a future study that analyzes the effects of implementation intentions upon automatization within prospective memory may reveal interesting results within a child sample. The appertaining research question would be: *do children automatize prospective memory responding throughout an experiment with numerous repetitions of a prospective memory cue and do implementation intentions foster automatization?*

4.5.4. Conditionality as a paradigmatic factor of prospective memory

In the general introduction of this thesis, I suggested a conceptual typology of prospective memory tasks in terms of nine paradigmatic factors (see Table 1). At this point, I would like to suggest a tenth factor that no study of which I am aware has systematically analyzed so far. This tenth factor is *conditionality.* Conditionality targets the distinction between intentions that have to be executed every time the prospective memory cue occurs and intentions that only have to be executed conditionally, that is as a function of situational requirements. Let me readopt the example from the general introduction above about telling a friend that he owes money to my brother. Imagine the situation as follows: after I asked my friend how he is, he tells me that he has just lost his job and is now suffering from severe financial problems. Under these circumstances I shall refrain from telling him that he owes 10 francs to my brother. Thus, although I did initiate the intention correctly, I will deliberately inhibit its execution. The prospective memory process is accordingly changed dramatically by this factor. In actuality, an additional phase is incorporated: a phase of questioning the appropriateness of the execution. This appropriateness can furthermore be tested morally (as in the above example) or logically. By "logically" I am referring to a situation where the execution is simply not possible. For example: I plan to go skiing on Christmas. Then Christmas day arrives and I remember my intention, but there is no snow. I will hence not be able to go skiing and thereby not execute my intention although I remembered it correctly.

Situations like these are not uncommon in everyday life. However, I am neither aware of any study in the field of prospective memory that systematically altered the conditionality of the intention execution, nor did the studies in this thesis examine this question empirically. However, with new insights from the results from the three studies presented above, it is possible to speculate about potential age-related differences.

The ability to inhibit an action, that is in this case the execution of the intended action, represents an important cognitive function when speaking about conditionality. Generally, inhibition performance depends on the availability and efficiency of attentional resources (Engle, Conway, Tuholski, & Shisler, 1995). One could thus argue that the efficient use of attentional resources represents an important prerequisite for incorporating the situational appropriateness (i.e., conditionality) of the intention-execution as it enables appropriate inhibition. And this might constitute the link to the results presented in this thesis. Older people and children have been described to generally show compromised attentional resources and compromised inhibition-abilities (Christ, White, Mandernach, & Keys, 2001). One would therefore assume children and old adults to more often fail to successfully inhibit the execution of the intention when the cue is indeed correctly detected but the situation is not appropriate (morally or logically). Considering the assumption of freed-up attentional resources through automatization, the conclusion stands to reason that these re-gained attentional resources can be reallocated to support efficient inhibition. Based on this line of argumentation, automatization might accordingly constitute a promising mechanism for more appropriate intention-execution, if existing and/or trainable especially in children and old adults. In contrast, one could also suggest the exact opposite. That is, from a different perspective it seems reasonable to assume that the more automatic prospective memory performance happens, the more demanding it is to successfully inhibit execution. As mentioned in study 3, an attention response that directs the attention automatically becomes difficult to suppress or ignore once it has been automatized (Schneider & Shiffrin, 1977). Automatization would accordingly lead to increased attentional resources that have to be allocated to interrupt the retrieval interval. The consequences for people with less efficient attentional resources but also less prominent automatization, that is for example older adults and maybe children, are thus left unresolved. As it becomes clear, the paradigmatic factor of conditionality should be examined in more detail in future studies, incorporating the electrophysiological measurement of automatization across the lifespan. A possible research question would be: *how does moral or logical conditionality influence prospective memory performance across the lifespan and what role does attention allocation play?*

An extended typology

The conceptually-driven typology depicted in point 1.3 of this thesis represented a first suggestion based on the most studied factors (a) – h)) and one that was examined in this thesis (factor i)). However, many more factors such as the just described *conditionality* may determine the specific type of prospective memory that is measured by a task. As illustrated in the intentional behavior and goal attainment model (see Figure 1), the different paradigmatic factors also influence the prospective memory phases as do the contributing cognitive functions. Accordingly, a future step might be to extend the suggested typology by two more columns: the assignment of the *phase(s)*, and the *specific cognitive function(s)* that are influenced by one specific factor. To conclusively do this, future studies are needed that systematically analyze separate phases and alter one factor at a time to control for its influence upon the cognitive functions.

4.6. Conclusion

In this thesis three research questions were examined. The first question aimed at analyzing prospective memory performance across the lifespan and the relative contribution of different components. Results confirmed the inverted U-shaped function and revealed greater dependence upon the development of the prospective component across the lifespan.

The second question concerned the differential temporal dynamics of the retrieval interval of successful and failed prospective memory across the lifespan. Data analyses showed that in successful prospective memory trials, participants from all age groups allocate the same cognitive resources. However, in failed prospective memory trials, we found significant age-related differences: children failed to switch between the ongoing activity and the prospective memory task, whereas young and older adults failed to detect the prospective memory cue.

And finally the third question addressed one specific paradigmatic factor, namely the possibility to examine differential attentional resource allocation in young and old adults. In this study, we found evidence for automatization processes of prospective memory responding throughout the progress of the experiment in young but not in older adults.

Based on this thesis it could be argued that aging is not simply “development in reverse” (Craik & Bialystok, 2008). The “rise” and the “fall” of prospective memory are more greatly determined by differential age-specific processes. Clearly it remains necessary for future studies to combine different paradigmatic factors in different age groups step by step and to embed and relate these findings appropriately. With this approach, I believe that it is possible to gradually increase our understanding of the conditions and requirements for successful prospective memory across the entire lifespan and answer the subsequent research questions of interest.

5. BIBLIOGRAPHY

Albinski, R., Kliegel, M., Sedek, G., & Kleszczewska-Albinska, A. (2012). Positive effects of subclinical depression in prospective memory and ongoing tasks in young and old adults. *Aging, Neuropsychology, and Cognition, 19*(1-2), 35-57.

Allan, K., & Rugg, M. D. (1998). Neural correlates of cued recall with and without retrieval of source memory. *Neuroreport, 9*(15), 3463-3466.

Altgassen, M., Kliegel, M., Brandimonte, M., & Filippello, P. (2009). Are older adults more social than younger adults? Social importance increases older adults' prospective memory performance. *Aging, Neuropsychology, and Cognition, 17*(3), 312-328.

Altgassen, M., Kliegel, M., & Martin, M. (2009). Event-based prospective memory in depression: The impact of cue focality. *Cognition & Emotion, 23*(6), 1041-1055.

Altgassen, M., Phillips, L. H., Henry, J. D., Rendell, P. G., & Kliegel, M. (2010). Emotional target cues eliminate age differences in prospective memory. *The Quarterly Journal of Experimental Psychology, 63*(6), 1057-1064.

Bailey, K. D. (1994). *Typologies and taxonomies: An introduction to classification techniques*. Sage University Paper series on Quantitative Applications in the Social Sciences, 07-102. Thousand Oaks, CA: Sage.

Bailey, P. E., Henry, J. D., Rendell, P. G., Phillips, L. H., & Kliegel, M. (2010). Dismantling the "age-prospective memory paradox": The classic laboratory paradigm simulated in a naturalistic setting. *The Quarterly Journal of Experimental Psychology, 63*(4), 646.

Baltes, P. B., & Baltes, M. M. (1990). Psychological perspectives on successful aging: The model of selective optimization with compensation. In P. B. Baltes & M. M. Baltes (Eds.), *Successful aging: Perspectives from the behavioral sciences* (pp. 1-34). New York: Cambridge University Press.

Banville, F., & Nolin, P. (2000). Mémoire prospective: analyse des liens entre les fonctions mnéstiques et les fonctions frontales chez des adultes victimes d'un traumatisme craniocérébral. *Revue de Neuropsychologie, 10*(2), 255-279.

Bisiacchi, P. S., Schiff, S., Ciccola, A., & Kliegel, M. (2009). The role of dual-task and task-switch in prospective memory: Behavioral data and neural correlates. *Neuropsychologia, 47*, 1362-1373.

Bogg, T., & Roberts, B. W. (2004). Conscientiousness and health-related behaviors: a meta-analysis of the leading behavioral contributors to mortality. *Psychological Bulletin, 130*(6), 887-919.

Brainerd, C. J., Reyna, V. F., Howe, M. L., Kingma, J., & Guttentag, R. E. (1990). The Development of Forgetting and Reminiscence. *Monographs of the Society for Research in Child Development, 55*(3/4), i-109.

Brand, M. (1984). *Intending and acting*. Cambridge, MA: MIT Press.

Brandimonte, M., Einstein, G. O., & McDaniel, M. A. (1996). *Prospective memory: Theory and applications*. Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Burgess, P. W., Gonen-Yaacovi, G., & Volle, E. (2011). Functional neuroimaging studies of prospective memory: What have we learnt so far? *Neuropsychologia, 49*(8), 2246-2257.

Burgess, P. W., Quayle, A., & Frith, C. D. (2001). Brain regions involved in prospective memory as determined by positron emission tomography. *Neuropsychologia, 39*(6), 545-555.

Ceci, S. J., Baker, J. G., & Bronfenbrenner, U. (1988). Prospective remembering, temporal calibration, and context. In M. M. Gruneberg, P. E. Morris & R. N. Sykes (Eds.), *Practical aspects of memory: Current research and issues* (Vol. 1, pp. 360-365). New York: Wiley.

Chasteen, A. L., Park, D. C., & Schwarz, N. (2001). Implementation intentions and facilitation of prospective memory. *Psychological Science, 12*(6), 457-461.

Christ, S. E., White, D. A., Mandernach, T., & Keys, B. A. (2001). Inhibitory control across the life span. *Developmental Neuropsychology, 20*(3), 653-669.

Cockburn, J., & Smith, P. T. (1988). Effects of age and intelligence on everyday memory tasks. In M. M. Gruneberg, P. E. Morris & R. N. Sykes (Eds.), *Practical aspects of memory: Current research and issues.* (Vol. 2: Clinical and educational implications, pp. 132-136). Chichester, U.K.: Wiley.

Cohen, A. L., Dixon, R. A., Lindsay, D. S., & Masson, M. E. J. (2003). The effect of perceptual distinctiveness on the prospective and retrospective components of prospective memory in young and old adults. *Canadian Journal of Experimental Psychology, 57*(4), 274-289.

Cohen, A. L., & Gollwitzer, P. M. (2008). The cost of remembering to remember: Cognitive load and implementation intentions influence ongoing task performance. In M. Kliegel, M. A. McDaniel & G. O. Einstein (Eds.), *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives* (pp. 367-390). New York: Lawrence Erlbaum Associates.

Cohen, A. L., West, R. L., & Craik, F. I. M. (2001). Modulation of the prospective and retrospective components of memory for intentions in younger and older adults. *Aging, Neuropsychology, and Cognition, 8*, 1-13.

Cohen, J. D., & O'Reilly, R. C. (1996). A preliminiary theory of the interactions between prefrontal cortex and hippocampus that contribute to planning and prospective memory. In M. Brandimonte, G. O. Einstein & M. A. McDaniel (Eds.), *Prospective memory: theory and applications* (pp. 267-295). Mahwah, NJ: Lawrence Erlbaum Assiciates Inc.

Craik, F. I. M. (1986). A functional account of age differences in memory. In F. Klix & H. Hagendorf (Eds.), *Human memory and cognitive capabilities: Mechanisms and performances* (pp. 409-422). Amsterdam: Elsevier-North-Holland.

Craik, F. I. M., & Bialystok, E. (2008). Lifespan cognitive development: The roles of representation and control. In F. I. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition (3rd edition)* (pp. 557-601). New York: Psychology Press.

Craik, F. I. M., & Kerr, S. A. (1996). Commentary: Prospective memory, aging, and lapses of intention. In M. Brandimonte, G. O. Einstein & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 227-237). Mahwah, NJ: Lawrence Erlbaum Associates.

Cuttler, C., & Graf, P. (2007). Personality predicts prospective memory task performance: An adult lifespan study. *Scandinavian Journal of Psychology, 48*, 215-231.

De Luca, C. R., Wood, S. J., Anderson, V., Buchanan, J. A., Proffitt, T. M., Mahony, K., et al. (2003). Normative data from the Cantab. I: Development of executive function over the lifespan. *Journal of Clinical and Experimental Neuropsychology, 25*(2), 242-254.

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods, 134*, 9-21.

Dobbs, A. R., & Reeves, M. B. (1996). Prospective memory: More than memory. In M. Brandimonte, G. O. Einstein & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 199-226). Mahwah, NJ: Lawrence Erlbaum Associates.

Dobbs, A. R., & Rule, B. G. (1987). Prospective memory and self-reports of memory abilities in older adults. *Canadian Journal of Psychology, 41*(2), 209-222.

d'Ydewalle, G., Bouckaert, D., & Brunfaut, E. (2001). Age-related differences and complexity of ongoing activities in time- and event-based prospective memory. *American Journal of Psychology, 114*(3), 411-423.

Dywan, J., & Jacoby, L. (1990). Effects of aging on source monitoring: differences in susceptibility to false fame. *Psychology and Aging, 5*(3), 379-387.

Einstein, G. O., Holland, L. J., McDaniel, M. A., & Guynn, M. J. (1992). Age-related deficits in prospective memory: The influence of task complexity. *Psychology and Aging, 7*(3), 471-478.

Einstein, G. O., Marsh, R. L., Manzi, M., Cochran, B., & Baker, M. (2000). Prospective memory and aging: Forgetting intention over short delays. *Psychology and Aging, 15*(4), 671-683.

Einstein, G. O., & McDaniel, M. A. (1990). Normal aging and prospective memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 16*(4), 717-726.

Einstein, G. O., & McDaniel, M. A. (1996). Retrieval processes in prospective memory: Theoretical approaches and some new empirical findings. In M. Brandimonte, G. O. Einstein & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 115-141). Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Einstein, G. O., & McDaniel, M. A. (2005). Prospective memory: Multiple retrieval processes. *Current Directions in Psychological Sciences, 14*, 286-290.

Einstein, G. O., McDaniel, M. A., Richardson, S. L., Guynn, M. J., & Cunfer, A. R. (1995). Aging and prospective memory: examining the influences of self-initiated retrieval processes. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 21*(4), 996-1007.

Einstein, G. O., McDaniel, M. A., Williford, C. L., Pagan, J. L., & Dismukes, R. K. (2003). Forgetting of intentions in demanding situations is rapid. *Journal of Experimental Psychology. Applied, 9*(3), 147-162.

Ellis, J. (1996). Prospective memory or the realization of delayed intentions: A conceptual framework for research. In M. Brandimonte, G. O. Einstein & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 1-22). Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Ellis, J., & Freeman, J. E. (2008). Ten years on: Realizing delayed intentions. In M. Kliegel, M. A. McDaniel & G. O. Einstein (Eds.), *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives* (pp. 1-27). New York: Lawrence Erlbaum Associates.

Ellis, J., & Kvavilashvili, L. (2001). Prospective memory in 2000: Past, present, and future directions. *Applied Cognitive Psychology, 14*(7), 1-9.

Ellis, J., Kvavilashvili, L., & Milne, A. (1999). Experimental tests of prospective remembering: the influence of cue-event frequency on performance. *British Journal of Psychology, 90 (Pt. 1)*, 9-23.

Engle, R. W., Conway, A. R. A., Tuholski, S. W., & Shisler, R. J. (1995). A resource account of inhibition. *Psychological Science, 6*(2), 122-125.

Freund, A. M., & Baltes, P. B. (1998). Selection, optimization, and compensation as strategies of life management: Correlations with subjective indicators of successful aging. *Psychology and Aging, 13*(4), 531-543.

Gathercole, S. E. (1999). Cognitive approaches to the development of short-term memory. *Trends in Cognitive Sciences, 3*(11), 410-419.

Giedd, J. N., Blumenthal, J., Jeffries, N. O., Castellanos, F. X., Liu, H., Zijdenbos, A., et al. (1999). Brain development during childhood and adolescence: A longitudinal MRI study. *Nature Neuroscience, 2*(10), 861-863.

Glisky, E. L. (2007). Changes in cognitive function in human aging. In D. R. Riddle (Ed.), *Brain aging: Models, methods, and mechanisms* (pp. 3-20). Boca Raton: CRC Press.

Gollwitzer, P. M. (1993). Goal achievement: The role of intentions. *European Review of Social Psychology, 4*(1), 141-185.

Gollwitzer, P. M., & Sheeran, P. (2006). Implementation intentions and goal achievement: A meta-analysis of effects and processes. *Advances in Experimental Social Psychology*, 69-119.

Goschke, T., & Kuhl, J. (1993). Representation of intentions: Persisting activation in memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 19*, 1211-1226.

Goschke, T., & Kuhl, J. (1996). Remembering what to do: explicit and implicit memory for intentions. In M. Brandimonte, G. O. Einstein & M. A. McDaniel (Eds.), *Prospective memory: theory and applications* (pp. 53-91). Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Grady, C. L., & Craik, F. I. M. (2000). Changes in memory processing with age. *Current Opinion in Neurobiology, 10*, 224-231.
Guajardo, N. R., & Best, D. L. (2000). Do preschoolers remember what to do? Incentive and external cues in prospective memory. *Cognitive Development, 15*, 75-97.
Guynn, M. J. (2008). Theory of monitoring in prospective memory: Instantiating a retrieval mode and periodic target checking. In M. Kliegel, M. A. McDaniel & G. O. Einstein (Eds.), *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives* (pp. 53-76). New York: Erlbaum.
Guynn, M. J., McDaniel, M. A., & Einstein, G. O. (1998). Prospective memory: When reminders fail. *Memory and Cognition, 26*(2), 287-298.
Guynn, M. J., McDaniel, M. A., & Einstein, G. O. (2001). Remembering to perform actions: A different type of memory? In H. D. Zimmer, R. L. Cohen, M. J. Guynn, J. Engelkamp, R. Kormi-Nouri & M. A. Foley (Eds.), *Memory for action: A distinct form of episodic memory?* (pp. 25-48). New York: Oxford University Press.
Harris, L. M. (1999). Mood and prospective memory. *Memory, 7*(1), 117-127.
Hasher, L., & Zacks, R. T. (1979). Automatic and effortful processes in memory. *Journal of Experimental Psychology: General, 108*(3), 356-388.
Henry, J. D., MacLeod, M. S., Phillips, L. H., & Crawford, J. R. (2004). A meta-analytic review of prospective memory and aging. *Psychology and Aging, 19*(1), 27-39.
Hicks, J. L., Marsh, R. L., & Russell, E. J. (2000). The properties of retention intervals and their affect on retaining prospective memories. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 26*(5), 1160-1169.
Huttenlocher, P. R., & Dabholkar, A. S. (1997). Regional differences in synaptogenesis in human cerebral cortex. *The Journal of Comparative Neurology, 387*, 167-178.
Jäncke, L. (2004). Neuropsychologie des Alterns. In A. Kruse & M. Martin (Eds.), *Enzyklopädie der Gerontologie* (pp. 207-223). Bern: Verlag Hans Huber.
Jasper, H. H. (1958). The ten-twenty electrode system of the international federation. *Electroencephalography and Clinical Neurophysiology, 10*, 371-375.
Jennings, J. M., & Jacoby, L. L. (1993). Automatic versus intentional uses of memory: Aging, attention, and control. *Psychology and Aging, 8*(2), 283-293.
Kausler, D. H. (1994). *Learning and memory in normal aging*. New York: Academic Press.
Kerns, K. A. (2000). The CyberCruiser: An investigation of development of prospective memory in children. *Journal of International Neuropsychological Society, 6*(1), 62-70.
Kidder, D. P., Park, D. C., Hertzog, C., & Morrell, R. W. (1997). Prospective memory and aging: The effects of working memory and prospective memory task load. *Aging Neuropsychology and Cognition, 4*, 93-112.
Kliegel, M., Eschen, A., & Thöne-Otto, A. I. T. (2004). Planning and realization of complex intentions in traumatic brain injury and normal aging. *Brain and Cognition, 56*(1), 43-54.
Kliegel, M., & Jäger, T. (2006). Delayed-execute prospective memory performance: the effects of age and working memory. *Developmental Neuropsychology, 30*(3), 819-843.
Kliegel, M., & Jäger, T. (2007). The effects of age and cue-action reminders on event-based prospective memory performance in preschoolers. *Cognitive Development, 22*, 33-46.
Kliegel, M., Mackinlay, R., & Jäger, T. (2008). A lifespan approach to the development of complex prospective memory. In M. Kliegel, M. A. McDaniel & G. O. Einstein (Eds.), *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives* (pp. 187-216). New York: Erlbaum.
Kliegel, M., & Martin, M. (2003). Prospective memory research: Why is it relevant? *International Journal of Psychology, 38*, 193-194.
Kliegel, M., Martin, M., McDaniel, M. A., & Einstein, G. O. (2002). Complex prospective memory and executive control of working memory: A process model. *Psychology Science, 44*, 303-318.

Kliegel, M., Martin, M., McDaniel, M. A., & Einstein, G. O. (2004). Importance effects on performance in event-based prospective memory tasks. *Memory, 12*(5), 553-561.

Kliegel, M., Martin, M., McDaniel, M. A., Einstein, G. O., & Moor, C. (2007). Realizing complex delayed intentions in young and old adults: The role of planning aids. *Memory and Cognition, 35*(7), 1735-1746.

Kliegel, M., Martin, M., & Moor, C. (2003). Prospective memory and ageing: Is task importance relevant? *International Journal of Psychology, 38*(4), 207-214.

Kliegel, M., McDaniel, M. A., & Einstein, G. O. (2000). Plan formation, retention, and execution in prospective memory: A new approach and age-related effects. *Memory and Cognition, 28*(6), 1041-1049.

Kliegel, M., McDaniel, M. A., & Einstein, G. O. (2008). *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives*. Mahwah: Erlbaum.

Kliegl, R., Smith, J., & Baltes, P. B. (1989). Testing-the-limits and the study of adult age differences in cognitive plasticity of a mnemonic skill. *Developmental Psychology, 25*(2), 247-256.

Knight, J. B., Ethridge, L. E., Marsh, R. L., & Clementz, B. A. (2010). Neural correlates of attentional and mnemonic processing in event-based prospective memory. *Frontiers in Human Neuroscience, 4*, 1-13.

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology, 38*(3), 557-577.

Kramer, A. F., Larish, J. L., Weber, T. A., & Bardell, L. (1999). Training for executive control: Task coordination strategies and aging. In *Attention and performance XVII: Cognitive regulation of performance: Interaction of theory and application.* (pp. 617-652): Cambridge, MA, US: The MIT Press.

Kray, J., Eber, J., & Lindenberger, U. (2004). Age differences in executive functioning across the lifespan: The role of verbalization in task preparation. *Acta Psychologica, 115*, 143-165.

Kvavilashvili, L. (1992). Remembering intentions: A critical review of existing experimental paradigms. *Applied Cognitive Psychology, 6*(6), 507-524.

Kvavilashvili, L., & Ellis, J. (1996). Varieties of intention: Some distinctions and classifications. In M. Brandimonte, G. O. Einstein & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 23-51). Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Kvavilashvili, L., Kyle, F. E., & Messer, D. J. (2008). The development of prospective memory in children: Methodological issues, empirical findings, and future directions. In M. Kliegel, M. A. McDaniel & G. O. Einstein (Eds.), *Prospective Memory: Cognitive, Neuroscience, Developmental, and Applied Perspectives* (pp. 115-140). Mahwah: Lawrence Erlbaum Associates.

Kvavilashvili, L., Messer, D. J., & Ebdon, P. (2001). Prospective memory in children: The effects of age and task interruption. *Developmental Psychology, 37*(3), 418-430.

Lewin, K. (1926). Vorsatz, Wille und Bedürfnis - Untersuchungen zur Handlungs- und Affekt-Psychologie. *Psychologische Forschung, 4*, 1-39.

Lezak, M. D. (1995). *Neuropsychological assessment* (3 ed.). New York: Oxford University Press.

Liu, L. L., & Park, D. C. (2004). Aging and medical adherence: The use of automatic processes to achieve effortful things. *Psychology and Aging, 19*(2), 318-325.

Lobaugh, N. J., West, R. L., & McIntosh, A. R. (2001). Spatiotemporal analysis of experimental differences in event-related potential data with partial least squares. *Psychophysiology, 38*(3), 517-530.

Logie, R. H., Maylor, E. A., Della Sala, S., & Smith, G. (2004). Working memory in event- and time-based prospective memory tasks: Effect of secondary demand and age. *European Journal of Cognitive Psychology, 16*, 441-456.

Louro, M., Pieters, R., & Zeelenberg, M. (2007). Dynamics of multiple-goal pursuit. *Journal of Personality and Social Psychology, 93*(2), 174-193.

Luck, S. J. (2005). *An introduction to the event-related potential technique*. Cambridge, MA: The MIT Press.

Mantyla, T., & Nilsson, L. G. (1997). Remembering to remember in adulthood: A population-based study on aging and prospective memory. *Aging Neuropsychology and Cognition, 4*, 81-92.

Marsh, R. L., Hicks, J. L., & Bink, M. L. (1998). Activation of completed, uncompleted, and partially completed intentions. *Journal of Experimental Psychology. Learning, Memory, and Cognition,* pp. 350-361.

Marsh, R. L., Hicks, J. L., & Watson, V. (2002). The dynamics of intention retrieval and coordination of action in event-based prospective memory. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 28*, 652-659.

Martin, M., & Kliegel, M. (2003). Die Entwicklung komplexer prospektiver Gedächtnisleistung im Kindesalter. *Zeitschrift für Entwicklungspsychologie und Pädagogische Psychologie, 35*(2), 75-82.

Martin, M., Kliegel, M., & McDaniel, M. A. (2003). The involvement of executive functions in prospective memory performance of adults. *International Journal of Psychology, 38*(4), 195-206.

Mattli, F., Zöllig, J., & West, R. (2011). Age-related differences in the temporal dynamics of prospective memory retrieval: A lifespan approach. *Neuropsychologia, 49*(12), 3494-3504.

Maylor, E. A. (1990). Age and prospective memory. *The Quarterly Journal of Experimental Psychology, 42*(3), 471-493.

Maylor, E. A. (1996). Does prospective memory decline with age? In M. Brandimonte, G. O. Einstein & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 173-197). Mahwah, NJ: Lawrence Erlbaum Associates.

Maylor, E. A., & Logie, R. H. (2010). A large-scale comparison of prospective and retrospective memory development form childhood to middle age. *The Quarterly Journal of Experimental Psychology, 63*(3), 442-451.

McDaniel, M. A., Bugg, J. M., Ramuschkat, G. M., Kliegel, M., & Einstein, G. O. (2009). Repetition errors in habitual prospective memory: elimination of age differences via complex actions or appropriate resource allocation. *Aging, Neuropsychology, and Cognition, 16*(5), 563-588.

McDaniel, M. A., & Einstein, G. O. (2000). Strategic and automatic processes in prospective memory retrieval: A multiprocess framework. *Applied Cognitive Psychology, 14*, 127-144.

McDaniel, M. A., & Einstein, G. O. (2007). *Prospective memory: An overview and synthesis of an emerging field*. Thousand Oaks, CA: Sage Publications.

McDaniel, M. A., & Einstein, G. O. (2008). Prospective memory and aging: Old issues and new questions. In S. M. Hofer & D. F. Alwin (Eds.), *Handbook of cognitive aging: interdisciplinary perspectives* (pp. 168-180). Los Angeles: Sage Publications, Inc.

McDaniel, M. A., Einstein, G. O., & Rendell, P. G. (2008). The puzzle of inconsistent age-related declines in prospective memory. In M. Kliegel, M. A. McDaniel & G. O. Einstein (Eds.), *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives* (pp. 141-160). New York: Lawrence Erlbaum Associates.

McDaniel, M. A., Einstein, G. O., Stout, A. C., & Morgan, Z. (2003). Aging and maintaining intentions over delays: do it or lose it. *Psychology and Aging, 18*(4), 823-835.

McDaniel, M. A., Glisky, E. L., Rubin, S. R., Guynn, M. J., & Routhieaux, B. C. (1999). Prospective memory: A neuropsychological study. *Neuropsychology, 13*(1), 103-110.

McDaniel, M. A., Robinson-Riegler, B., & Einstein, G. O. (1998). Prospective remembering: perceptually driven or conceptually driven processes? *Memory and Cognition, 26*(1), 121-134.

Meacham, J. A., & Leiman, B. (1982). Remembering to perform future actions. In U. Neisser (Ed.), *Memory observed* (pp. 327-336). San Francisco: Freeman.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "Frontal Lobe" tasks: a latent variable analysis. *Cognitive Psychology, 41*, 49-100.

Naveh-Benjamin, M. (2000). Adult Age Differences in Memory Performance: Tests of an Associative Deficit Hypothesis. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 26*(5), 1170-1187.

Nyberg, L., McIntosh, A. R., Houle, S., Nilsson, L. G., & Tulving, E. (1996). Activation of medial temporal structures during episodic memory retrieval. *Nature, 380*, 715-717.

Paller, K. A., & Wagner, A. D. (2002). Observing the transformation of experience into memory. *Trends in Cognitive Sciences, 6*(2), 93-102.

Park, D. C., Gutchess, A. H., Meade, M. L., & Stine-Morrow, E. A. (2007). Improving cognitive function in older adults: nontraditional approaches. *Journal of Gerontology: Series B, 62B*(Special Issue I), 45-52.

Park, D. C., Hertzog, C., Kidder, D. P., Morrell, R. W., & Mayhorn, C. B. (1997). Effect of age on event-based and time-based prospective memory. *Psychology and Aging, 12*(2), 314-327.

Park, D. C., Lautenschlager, G., Hedden, T., Davidson, N. S., Smith, A. D., & Smith, P. K. (2002). Models of visuospatial and verbal memory across the adult life span. *Psychology and Aging, 17*(2), 299-320.

Perlmutter, M., & Lange, G. (1978). A developmental analysis of recall - recognition distinctions. In P. A. Ornstein (Ed.), *Memory development in children*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Phillips, L. H., Henry, J. D., & Martin, M. (2008). Adult aging and prospective memory: The importance of ecological validity. In M. Kliegel, M. A. McDaniel & G. O. Einstein (Eds.), *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives* (pp. 161-185). New York: Lawrence Erlbaum Associates.

Raz, N., Lindenberger, U., Rodrigue, K. M., Kennedy, K. M., Head, D., Williamson, A., et al. (2005). Regional brain changes in aging healthy adults: General trends, individual differences and modifiers. *Cerebral Cortex, 15*(11), 1676-1689.

Rendell, P. G., & Craik, F. I. M. (2000). Virtual week and actual week: Age-related differences in prospective memory. *Applied Cognitive Psychology, 14*, 43-62.

Rendell, P. G., Phillips, L. H., Henry, J. D., T., B.-R., X., d. l. P. G., Altgassen, M., et al. (2011). Prospective memory, emotional valence and ageing. *Cognition and Emotion, 25*(5), 916.

Rendell, P. G., & Thomson, D. M. (1993). The effect of aging on remembering to remember: An investigation of simulated medication regimens. *Australian Journal of Ageing, 12*, 11-18.

Rendell, P. G., & Thomson, D. M. (1999). Aging and prospective memory: differences between naturalistic and laboratory tasks. *The Journals of Gerontology. Series B, Psychological Sciences and Social Sciences, 54*(4), 256-269.

Salthouse, T. A. (1991). *Theoretical perspectives on cognitive aging*. Hillsdale, NJ: Erlbaum.

Sauseng, P., Klimesch, W., Freunberger, R., Pecherstorfer, T., Hanslmayr, S., & Doppelmayr, M. (2006). Relevance of EEG alpha and theta oscillations during task switching. *Exp Brain Res, 170*(3), 295-301.

Schneider, W., & Pressley, M. (1997). *Memory development between two and twenty* (Second ed.). Mahwah, NJ: Erlbaum.

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84*(1), 1-54.

Schnitzspahn, K. M., Ihle, A., Henry, J. D., Rendell, P. G., & Kliegel, M. (2010). The age-prospective memory-paradox: an exploration of possible mechanisms. *International Psychogeriatrics, 23*(4), 583-592.

Shallice, T., & Burgess, P. W. (1991). Deficits in strategy application following frontal lobe damage in man. *Brain, 114,* 727.

Shindler, A. G., Caplan, L. R., & Hier, D. B. (1984). Intrusions and perseverations. *Brain and Language, 23*(1), 148-158.

Simon, H. A. (1994). The bottleneck of attention: Connecting thought with motivation. In W. D. Spaulding (Ed.), *Integrative views of motivation, cognition, and emotion* (pp. 1-21). Lincoln: University of Nebraska Press.

Simons, J. S., Schölvinck, M. L., Gilbert, S. J., Frith, C. D., & Burgess, P. W. (2006). Differential components of prospective memory?: Evidence from fMRI. *Neuropsychologia, 44*(8), 1388-1397.

Smith, G., Della Sala, S., Logie, R. H., & Maylor, E. A. (2000). Prospective and retrospective memory in normal ageing and dementia: A questionnaire study. *Memory, 8*(5), 311-321.

Smith, R. E. (2003). The cost of remembering to remember in event-based prospective memory: Investigating the capacity demands of delayed intention performance. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(3), 347-361.

Smith, R. E. (2008). Connecting the past and the future: Attention, memory, and delayed intentions. In M. Kliegel, M. A. McDaniel & G. O. Einstein (Eds.), *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives* (pp. 29-52). New York: Lawrence Erlbaum Associates.

Smith, R. E., & Bayen, U. J. (2004). A multinomial model of event-based prospective memory. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 30*(4), 756-777.

Smith, R. E., & Bayen, U. J. (2006). The source of adult age differences in event-based prospective memory: A multinomial modeling approach. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(3), 623-635.

Smith, R. E., Bayen, U. J., & Martin, C. (2010). The cognitive processes underlying event-based prospective memory in school age children and young adults: a formal model-based study. *Developmental Psychology, 46*(1), 230-244.

Smith, R. E., Persyn, D., & Butler, P. (2011). Prospective memory, personality, and working memory: A formal modeling approach. *Journal of Psychology, 219*(2), 108-116.

Snodgrass, J. G., & Vanderwart, M. (1980). A standardized set of 260 pictures: Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology: Human Learning and Memory, 6*(2), 174-215.

Somerville, S. C., Wellman, H. M., & Cultice, J. C. (1983). Young children's deliberate reminding. *Journal of Genetic Psychology, 143*, 87-96.

Sowell, E. R., Peterson, B. S., Thompson, P. M., Welcome, S. E., Henkenius, A. L., & Toga, A. W. (2003). Mapping cortical change across the human life span. *Nature Neuroscience, 6*(3), 309-315.

Sowell, E. R., Thompson, P. M., Holmes, C. J., Jernigan, T. L., & Toga, A. W. (1999). In vivo evidence for post-adolescent brain maturation in frontal and striatal regions. *Nature Neuroscience, 2*(10), 859-861.

Stone, M., Dismukes, K., & Remington, R. (2001). Prospective memory in dynamic environments: Effects of load, delay, and phonological rehearsal. *Memory, 9*(3), 165-176.

Strutt, G. F., Anderson, D. R., & Well, A. D. (1975). A developmental study of the effects of irrelevant information on speeded classification. *Journal of Experimental Child Psychology, 20*(1), 127-135.

Uttl, B. (2008). Transparent meta-analysis of prospective memory and aging. *PLoS ONE, 3*(2), e1568.

Verhaeghen, P., & Cerella, J. (2002). Aging, executive control, and attention: a review of meta-analyses. *Neuroscience and Biobehavioral Reviews, 26*(7), 849-857.

Verplanken, B., & Aarts, H. (1999). Habit, Attitude, and Planned Behaviour: Is Habit an Empty Construct or an Interesting Case of Goal-directed Automaticity? *European Review of Social Psychology, 10*(1), 101-134.

West, R. L. (1996). An application of prefrontal cortex function theory to cognitive aging. *Psychological Bulletin, 120*(2), 272-292.

West, R. L. (2005). The neural basis of age-related declines in prospective memory. In R. Cabeza, L. Nyberg & D. C. Park (Eds.), *Cognitive neuroscience of aging: Linking cognitive and cerebral aging* (pp. 246-264): Oxford University Press.

West, R. L. (2007). The influence of strategic monitoring on the neural correlates of prospective memory. *Memory and Cognition, 35*(5), 1034-1046.

West, R. L. (2011). The temporal dynamics of prospective memory: a review of the ERP and prospective memory literature. *Neuropsychologia, 49*, 2233-2245.
West, R. L., & Bowry, R. (2005). Effects of aging and working memory demands on prospective memory. *Psychophysiology, 42*(6), 698-712.
West, R. L., Bowry, R., & Krompinger, J. (2006). The effects of working memory demands on the neural correlates of prospective memory. *Neuropsychologia, 44*(2), 197-207.
West, R. L., & Covell, E. (2001). Effects of aging on event-related neural activity related to prospective memory. *NeuroReport, 12*(13), 2855-2858.
West, R. L., & Craik, F. I. M. (1999). Age-related decline in prospective memory: the roles of cue accessibility and cue sensitivity. *Psychology and Aging, 14*(2), 264-272.
West, R. L., & Craik, F. I. M. (2001). Influences on the efficiency of prospective memory in younger and older adults. *Psychology and Aging, 16*(4), 682-696.
West, R. L., Herndon, R. W., & Covell, E. (2003). Neural correlates of age-related declines in the formation and realization of delayed intentions. *Psychology and Aging, 18*(3), 461-473.
West, R. L., Herndon, R. W., & Crewdson, S. J. (2001). Neural activity associated with the realization of a delayed intention. *Cognitive Brain Research, 12*(1), 1-9.
West, R. L., Herndon, R. W., & Ross-Munroe, K. (2000). Event-related neural activity associated with prospective remembering. *Applied Cognitive Psychology, 14*, 115-126.
West, R. L., Jakubek, K., & Wymbs, N. (2002). Age-related declines in prospective memory: Behavioral and electrophysiological evidence. *Neuroscience and Biobehavioral Reviews, 26*(7), 827-833.
West, R. L., & Krompinger, J. (2005). Neural correlates of prospective and retrospective memory. *Neuropsychologia, 43*, 418-433.
West, R. L., Krompinger, J., & Bowry, R. (2005). Disruptions of preparatory attention contribute to failures of prospective memory. *Psychonomic Bulletin & Review, 12*(3), 502-507.
West, R. L., McNerney, M. W., & Travers, S. (2007). Gone but not forgotten: The effects of cancelled intentions on the neural correlates of prospective memory. *International Journal of Psychophysiology, 64*(3), 215-225.
West, R. L., & Ross-Munroe, K. (2002). Neural correlates of the formation and realization of delayed intentions. *Cognitive, Affective, and Behavioral Neuroscience, 2*(2), 162-173.
West, R. L., & Wymbs, N. (2004). Is detecting prospective cues the same as selecting targets? An ERP study. *Cognitive, Affective, and Behavioral Neuroscience, 4*(3), 354-363.
West, R. L., Wymbs, N., Jakubek, K., & Herndon, R. W. (2003). Effects of intention load and background context on prospective remembering: An event-related brain potential study. *Psychophysiology, 40*(2), 260-276.
Yang, T., Chan, R. C. K., & Shum, D. (2011). The development of prospective memory in typically developing children. *Neuropsychology, 25*(3), 342-352.
Zacks, R. T., Hasher, L., & Li, K. Z. H. (2000). Human memory. In F. I. Craik & T. A. Salthouse (Eds.), *The handbook of aging and cognition*. Mahwah, NJ: Lawrence Erlbaum.
Zelazo, P. D., Craik, F. I. M., & Booth, L. (2004). Executive function across the life span. *Acta Psychologica, 115*(2-3), 167-183.
Zimmermann, T. D., & Meier, B. (2006). The rise and decline of prospective memory performance across the lifespan. *The Quarterly Journal of Experimental Psychology, 59*(12), 2040-2046.
Zimmermann, T. D., & Meier, B. (2010). The effect of implementation intentions on prospective memory performance across the lifespan. *Applied Cognitive Psychology, 24*(5), 645-658.
Zöllig, J., & Eschen, A. (2009). Measuring compensation and its plasticity across the lifespan. *Restorative Neurology and Neuroscience, 27*(5), 421-433.

Zöllig, J., Martin, M., & Kliegel, M. (2010). Forming intentions successfully: Differential compensational mechanisms of adolescents and old adults. *Cortex, 46*, 575-589.

Zöllig, J., Mattli, F., Sutter, C., Aurelio, A., & Martin, M. (2012). Plasticity of prospective memory through a familiarization intervention in old adults. *Aging, Neuropsychology, and Cognition, 19*(1-2), 168-194.

Zöllig, J., West, R. L., Martin, M., Altgassen, M., Lemke, U., & Kliegel, M. (2007). Neural correlates of prospective memory across the lifespan. *Neuropsychologia, 45*(14), 3299-3314.